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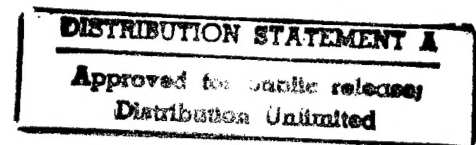
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# Improving NASA's Technology for Space Science

Committee on Space Science Technology

Aeronautics and Space Engineering

Commission on Engineering and Technology

Report of the

Committee on Space Science Technology

to the

# **Improving NASA's Technology for Space Science**

*Committee on Space Science Technology Planning*

**Aeronautics and Space Engineering Board  
Commission on Engineering and Technical Systems**

**Space Studies Board  
Commission on Physical Sciences, Mathematics, and Applications**

**National Research Council**

**National Academy Press  
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**NOTICE:** The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the panel responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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## PREFACE

In 1990, as an attempt to bring together the many research communities associated with space sciences and space engineering, the two boards of the National Research Council dedicated to recommending priorities and procedures for achieving the nation's civilian space program objectives—the Aeronautics and Space Engineering Board and the Space Studies Board—initiated a Joint Committee on Technology for Space Science and Applications. Late in 1991 and at the request of NASA, the Joint Committee agreed to review NASA's *Integrated Technology Plan* with an eye towards identifying means of optimizing the future development of technology for space science and applications. A new, larger committee was convened and a workshop was held in June 1992. This report contains the findings of that Committee, the Committee on Space Science Technology Planning.

The Committee had a specific charge to accomplish, which I believe we have addressed as well as possible given the scope of the task. For five days, representatives of the science and engineering communities, from NASA, industry, and academe, had an opportunity to discuss, argue, agree and disagree, and come to understand each other in ways never before possible. The new interactions and the insights they fostered have led to what is, in my opinion, a unique study with valuable information for the future of NASA. It is the Committee's belief that following the recommendations in this report can help NASA do a more effective job and give the taxpayers more value for their money.

Throughout history, new technology has gone hand in hand with scientific discovery. Sometimes new technology based on established scientific principles has led to new scientific discoveries, sometimes new scientific discoveries have brought forth new technologies and industries. No field of endeavor has been more technology-dependent than space-based research. NASA has a special responsibility to advance U.S. aerospace technology. Its science programs can serve to focus a portion of the investment in technology, but the objective is not simply to benefit science. The technologies themselves are vital NASA products and their development should involve all aspects of the nation with the ability to contribute.

I hope that the intentions of the Aeronautics and Space Engineering Board and the Space Studies Board to make this interaction a continuing one will be realized and such undertakings will continue into the future. On behalf of the committee members I thank those from NASA, NASA contractors, and academe, who provided the committee members with necessary information on key NASA programs and projects and enabled the committee to be sufficiently well-informed to deliver this wide-ranging report.

John H. McElroy, Chair  
Committee on Space Science Technology Planning

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# EXECUTIVE SUMMARY

## INTRODUCTION

The continued advance of the nation's space program is directly dependent upon the development and use of new technology. Technology is the foundation for every aspect of space missions and ground operations. The improvements in technology that will enable future advances are not only in device and system performance, but also in permitting missions to be carried out more rapidly and at lower cost. Although more can be done with current technology, NASA's recent call for new and innovative approaches should not be answered by employing only today's technologies; new technologies with revolutionary potential should be sought. The study reported here was performed to identify means to enhance the development of technologies for the space sciences and applications. (See Statement of Task, Appendix A.)

In the summer of 1992, when this study was conducted, most exploratory space technology development activities in NASA were concentrated in the Office of Aeronautics and Space Technology (OAST). Space science and applications activities were concentrated in NASA's Office of Space Science and Applications (OSSA). The Committee on Space Science Technology Planning was assembled by the National Research Council's Aeronautics and Space Engineering Board (ASEB) and Space Studies Board (SSB) to carry out the study. The Committee was convened in a week-long workshop in June 1992, and the preparation of the study report continued thereafter. In October 1992, as this report was being edited, a reorganization affecting NASA's science and technology offices was announced. Despite the reorganization, however, the goals and responsibilities previously assigned to OSSA and OAST are likely to endure and the results of this study should prove useful to their successor organizations. All references to OSSA and OAST should be taken to refer with equal facility to the past structure or the successor organizations.

### The Office of Aeronautics and Space Technology

OAST has been charged with technology development in support of other NASA entities, as well as for the nation's other civilian space activities. These responsibilities encompass, but also extend beyond, the needs of OSSA. Within OAST, funds are apportioned into a basic research program (the Base Program) and another program addressing specific future NASA missions (the Civil Space Technology Initiative or Focused Program). The funds in these programs represent the largest, most flexible, discretionary resources that NASA can apply to



creating technology-derived opportunities for the future. In fiscal year (FY) 1992, \$156 million was allocated to the Base Program and \$150 million to the Focused Program. Of these, OAST estimates that \$67.8 million in the Base Program and \$60.5 million in the Focused Program serve OSSA's needs. Obviously, the allocation of OAST's funds among technological opportunities and the oversight of selected development tasks should warrant careful attention from NASA management.

### The Integrated Technology Plan

The Advisory Committee on the Future of the U.S. Space Program recommended to NASA:

. . . that an agency-wide technology plan be developed with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds.

In response to this recommendation, OAST prepared the *Integrated Technology Plan for the Civil Space Program* (ITP). To begin the preparation of the ITP, OAST requested information regarding technology needs from each NASA mission office, including OSSA. The preparation of the ITP was a major effort that addressed the technology needs of all areas of NASA's space efforts, other government agencies, and the commercial space industry, as well as addressing past recommendations of advisory groups. The preparation of the ITP and its subsequent review by the NASA Space Systems and Technology Advisory Committee (SSTAC) were the principal elements leading to the current study.

### The Office of Space Science and Applications

OSSA is responsible for directing the part of NASA that uses the unique characteristics of space to conduct scientific studies of the Earth, solar system, and universe; to study the effects of low gravity on sensitive systems; and for practical purposes. OSSA has six science divisions: Astrophysics, Space Physics, Earth Science and Applications, Solar System Exploration, Life Sciences, and Microgravity Science and Applications. The FY 1992 budget was \$2.728 billion. A relatively small fraction of these funds (by OSSA estimate, \$48.8 million or 1.8%) is devoted to advanced technology development; it supports the comparatively near-term requirements of well-defined missions. To review the work of the science divisions and the related OAST support, the Committee employed four subcommittees: Astrophysics and Space Physics, Earth and Planetary Science, Life Sciences, and Microgravity Sciences.

## FINDINGS AND RECOMMENDATIONS

### General

NASA's new initiative for smaller, less expensive, and more frequent missions is not simply a response to budget pressures; it is a scientific and technical imperative. Efficient conduct of science and applications missions cannot be based solely upon intermittent, very large missions that require 10 to 20 years to complete. Mission time constants must be commensurate with the time constants of scientific understanding, competitive technological advances, and inherent changes in the systems under study (e.g., the Earth, its atmosphere, and oceans). This theme should be an important element of any agency-wide technology program.

With the establishment of judicious priorities, the present level of support allocated to OAST and OSSA should be sufficient to formulate a modest but responsive technology development program based on the key unmet needs of NASA's diverse science programs. However, the fraction of agency resources (at most \$177 million of \$14.3 billion) devoted to reducing technological risk in its major space science and applications programs is small, and does not appear adequate to reduce future risk appreciably or to make sufficient new technological advances available.

In spite of its pervasiveness and importance to NASA, there is no organized central control, information center, or focal point for all of NASA's technology development efforts, which now are spread throughout the agency. The NASA Administrator should act to establish a coordinating position with the clear responsibility to ensure cooperation between technology development efforts within different parts of NASA. An appropriate early task would be to extract information from the ITP to use in the formulation of an agency-wide working plan for technology for space science that is based on all of NASA's resources dedicated to this area.

### The OAST Focused Program

Better mechanisms are needed to ensure the transfer of OAST-developed technology to OSSA's flight missions. No efficient means exist to overcome the reluctance of OSSA managers to adopt unproven technology from OAST. Program and project managers are understandably hesitant to accept responsibility for completing technology development projects begun by OAST and to apply unproven new technologies to multi-million dollar science programs on an ad hoc basis. Better mechanisms are needed to ensure that the users of space technology maintain an investment in the OAST technology development efforts established to respond to their needs. OAST and OSSA divisions should agree during the earliest phases of each project initiated at OAST specifically in response to a science need how, and at what stage of development, transfer will occur.

Throughout its programs OAST should bring increased rigor (including external review) to determining not only which projects should be initiated or continued but which should be canceled. In a flat or low-growth funding environment this process will be extremely important to promote the viability of a program to meet the needs of space science and applications. It is critical that new innovations be welcomed even within a program that is unable to grow.

### **The OAST Base Program**

Because it is not configured to respond directly to the stated needs of user communities, the Base Program is not thoroughly described in the ITP and was not subject to in-depth scrutiny by the Committee. The Base Program serves both as a means to advance technology and to maintain organizational capability to perform space flight projects. The two are not necessarily compatible functions, attempting as they do to combine research excellence with sustenance of agency know-how. Special efforts should be made to make the work in the Base Program visible to the space science community so that latent capabilities can be captured and put to use wherever applicable. The program should be subject to more visible external review on a regular basis. As an investment of public resources, the quality of the Base Program must be scrutinized with the same intensity as the Focused Program. Responding to projected mission needs is important, but a portion of NASA's technology program must respond to new, even high-risk, ideas that may yield large advances. The avoidance of risk should not be elevated to such a position that innovative but unconventional concepts are summarily dismissed.

### **The Integrated Technology Plan**

The preparation of the ITP was a commendable and much-needed first step. But the ITP is only agency-wide in terms of integrating inputs from all of the NASA mission offices. It is not agency-wide in terms of being an expression of the priorities of NASA as a whole. It represents the integration of inputs by one office among several, but does not reflect the authoritative merger and ranking of these inputs by a management that oversees these offices of equal stature. In other words, it does not show the influence of the Office of the NASA Administrator or a relationship to a realistic agency-wide strategic plan.

Further, the ITP is not a *plan* in the sense of a statement of technical objectives, schedules, and estimated costs for the chosen tasks—presumably within an approved or agency-proposed budget. Rather, the ITP is a prospectus of development tasks most of which cannot be undertaken within either the existing budget or any budget that is likely to be available, based on the experiences of the last decade.

### The Office of Space Science and Applications

Technology development projects in OSSA are individually selected and undertaken by its divisions; there is no overarching OSSA technology development strategy or program. There is little consistency across the science divisions regarding technology development (criteria, process, etc.).

While some divisions have done so, e.g., the Astrophysics Division, not all divisions of OSSA have established formal technology planning procedures or assigned responsibility for technology planning. For example, the Committee found no formal process within the Earth Science and Applications and Life Sciences Divisions and a largely informal process within the Solar System Exploration Division that appears to have little involvement with the planetary sciences community. Each OSSA division that has not yet done so should act to formalize technology planning responsibilities to identify, coordinate, and report relevant work within the division. OSSA divisions should consider empowering existing advisory working groups for particular scientific areas to identify technology needs, and contribute to their evaluation by examining subsequent sets of consolidated division-wide technology needs.

Criteria were not presented to the Committee that could be used to determine which projects should be undertaken with OSSA divisions funds and which should be submitted to OAST for funding. In particular, it is not clear that the divisions have consistently requested technological assistance from OAST for their most basic technology problems.

Finally, the overall fraction of OSSA resources devoted to promoting advanced technology development is too small (\$48.8 million of \$2.728 billion) to enhance capabilities, reduce risk, and make new technological advances available for future space science and applications initiatives.

## INTRODUCTION

### STUDY ORIGINS

The role that advanced technology plays in the National Aeronautics and Space Administration's pursuit of the nation's civil space goals is self-evident. Technology underpins every aspect of space missions and ground operations. In common with other high-technology organizations, NASA must periodically assess its processes for selecting technology development tasks and choosing programs.

or optimizing the future development of technology for space science and applications (see Appendix A). As requested, this resulting study focuses on the technology needs of the NASA Office of Space Science and Applications (OSSA), and the relevant decision processes and programs of OSSA and the NASA Office of Aeronautics and Space Technology (OAST).

Two boards of the NRC, the Aeronautics and Space Engineering Board (ASEB) and the Space Studies Board (SSB), advise OAST and OSSA, respectively. These boards assembled a broadly representative committee of 26 engineers and scientists from industry, academia, and government: the Committee on Space Science Technology Planning. To perform this study the Committee reviewed the technology needs of the six OSSA science divisions, identifying gaps where possible; reviewed the processes by which the needs had been derived; and reviewed the OAST responses to the needs and the processes by which these had been derived. After completing the above, the Committee has suggested a number of modifications and actions to improve coordination and transfer of knowledge and technology between OSSA and OAST.

The Committee met on May 22, 1992 and June 22-26, 1992. The first meeting was devoted to briefings from OAST and OSSA officials on their programs and their perspectives on the requested study. The week-long workshop expanded upon those briefings in plenary session and permitted subcommittees to examine particular issues in more detail. Subcommittees were formed in four areas: astrophysics and space physics; earth and planetary sciences; life sciences; and microgravity sciences. Workshop participants are listed in Appendix B. In October 1992, the Administrator of NASA announced his intention to reorganize OAST and OSSA. OAST was divided into separate space and aeronautics organizations. OSSA was divided into separate organizations for different areas of space sciences and applications. As this

reorganization occurred during the editing of this report, the study committee had no opportunity to examine the reorganization. Despite the reorganization, however, the goals and responsibilities previously assigned to OSSA and OAST are likely to endure and the results of this study should prove useful to their successor organizations. Because of the changes in organization, and to avoid cumbersome sentences, all references to OSSA and OAST should be taken to refer with equal facility to the past structure or the successor organizations.

## NASA AND TECHNOLOGY DEVELOPMENT

The Office of Aeronautics and Space Technology has been the NASA office charged with funding and carrying out exploratory and proof-of-concept technology development in support of other NASA entities. OAST's mission statement for its Space Technology Directorate is to:

...provide technology for future civil space missions and provide a base of research and technology capabilities to serve all national space goals. [OAST shall] Identify, develop, validate and transfer technology to: increase mission safety and reliability; reduce program development and operations cost; enhance mission performance; and enable new missions. [OAST shall] Provide the capability to: advance technology in critical disciplines; and respond to unanticipated mission needs.<sup>1</sup>

In accordance with its mission, the Office of Space Science and Applications is:

... responsible for planning, directing, executing and evaluating that part of the overall NASA program that has the goal of using the unique characteristics of the space environment to conduct a scientific study of the universe, to understand how Earth works as an integrated system, to solve practical problems on Earth, and to provide the scientific and technological research foundation for expanding human presence beyond Earth orbit into the solar system.<sup>2</sup>

OAST's responsibilities encompass but extend considerably beyond serving OSSA's needs. OAST categorizes its efforts into two areas: basic and focused technology development. Basic research and development is supported by the Research and Technology Base Program, referred to as the Base Program. The Base Program addresses: aerothermodynamics, space energy conversion, propulsion, materials and structures, information and controls, human support, and space communications. Focused research and development is supported primarily by the Civil Space Technology Initiative and is divided into five technology thrusts for the support of space science, operations, transportation, platforms, and planetary surface exploration.

The funds allocated to OAST represented, and it is anticipated that those allocated to the successor Office of Advanced Concepts and Technology will continue to represent, the largest discretionary resources that NASA can apply to technology development. In fiscal year (FY) 1992, NASA invested \$306 million through OAST to create new technological capabilities. In focused research and development, \$13.5 million was allocated specifically to the space science thrust. An estimated \$27.7-\$47 million more from the \$150 million Civil Space Technology Initiative also contributed to space science technology. According to OAST, \$67.8 of the \$155.9 million in the Base Program contributed to space science objectives in a more general way.

OSSA divisions fund advanced technology development activities that are generally carried out in support of comparatively near-term requirements of well-defined missions. Ideally, OSSA's technology development activities would begin where those of OAST end, and would lead to jointly-developed flight hardware. OSSA has estimated that it invested \$48.8 million in technology development for the space sciences in FY 1992. These estimates and OAST's allocations, which do not include the cost of civil servants, are discussed in Appendix C.

Because NASA is inherently a high-technology organization, and because its programs are so diverse, technology development is a pervasive, distributed function across all of NASA's offices, programs, and centers. Technology development may occur within the framework of research or operational missions, or in support of projected future needs. Within NASA, each program and office is largely free to choose its technology according to its own perspectives, establish its own priorities for development, and conduct its programs according to its own procedures.

There are few incentives to promote collaboration or the transfer of technology across program or NASA center boundaries. Thus, the collaboration between OSSA and OAST that is a principal subject of this report has been a voluntary one. The complexities of NASA organizational structure and the separate budgets employed to fund activities produce the potential for impediments to technology transfer.

One of the most powerful pressures for the integration of programs and activities ordinarily occurs in the development of a budget. The overall NASA budget, however, can be depicted as largely independent segments that are separately examined in the budget process. Each office's budget is individually defended before the NASA Administrator, the Office of Management and Budget, and Congress. Therefore, each office naturally feels that it "owns" and has earned its individual budget. Except in the broadest sense, the coordination of activities is left to voluntary efforts among managers.

During the 1980s and early 1990s, both OAST and OSSA experienced significant but inconsistent budget growth. From 1980 to 1992, in real dollar terms, OSSA's budget grew approximately 70 percent, and OAST's space technology budget grew approximately 55 percent. The OSSA and OAST space technology budgets from 1980 to 1992 are shown in Figure 1.



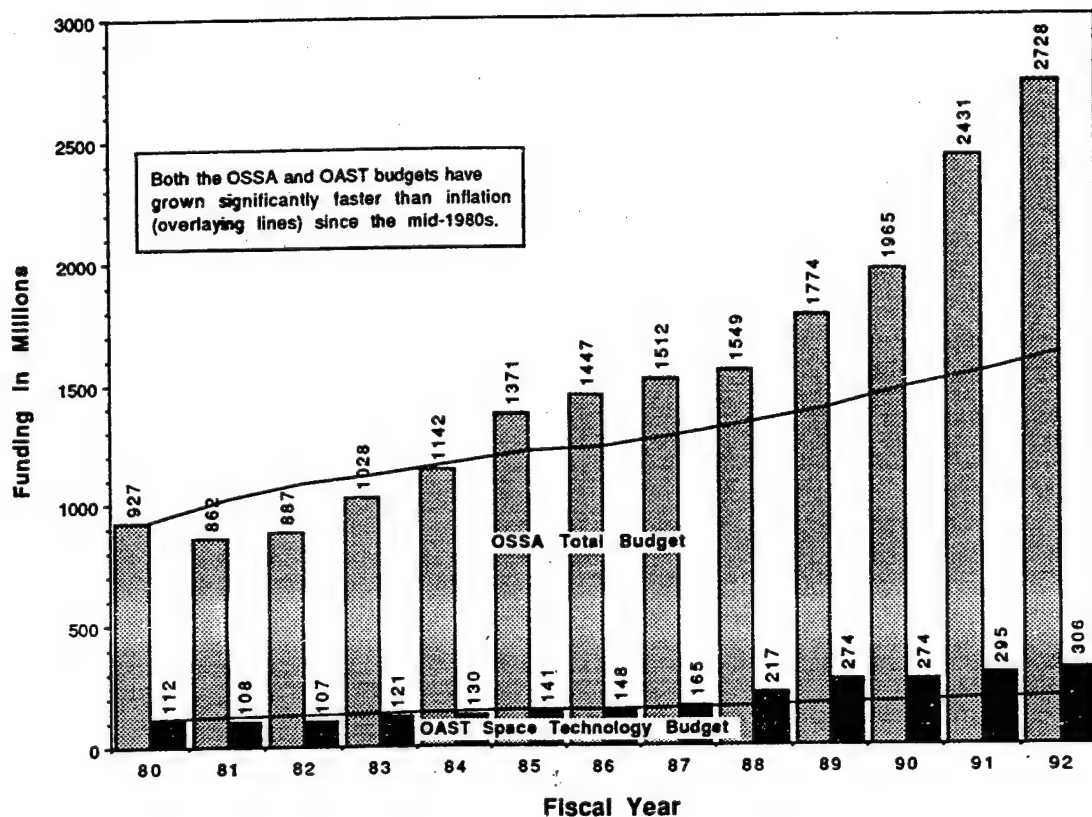


Figure 1 OSSA total and OAST space technology budgets 1980-1992.

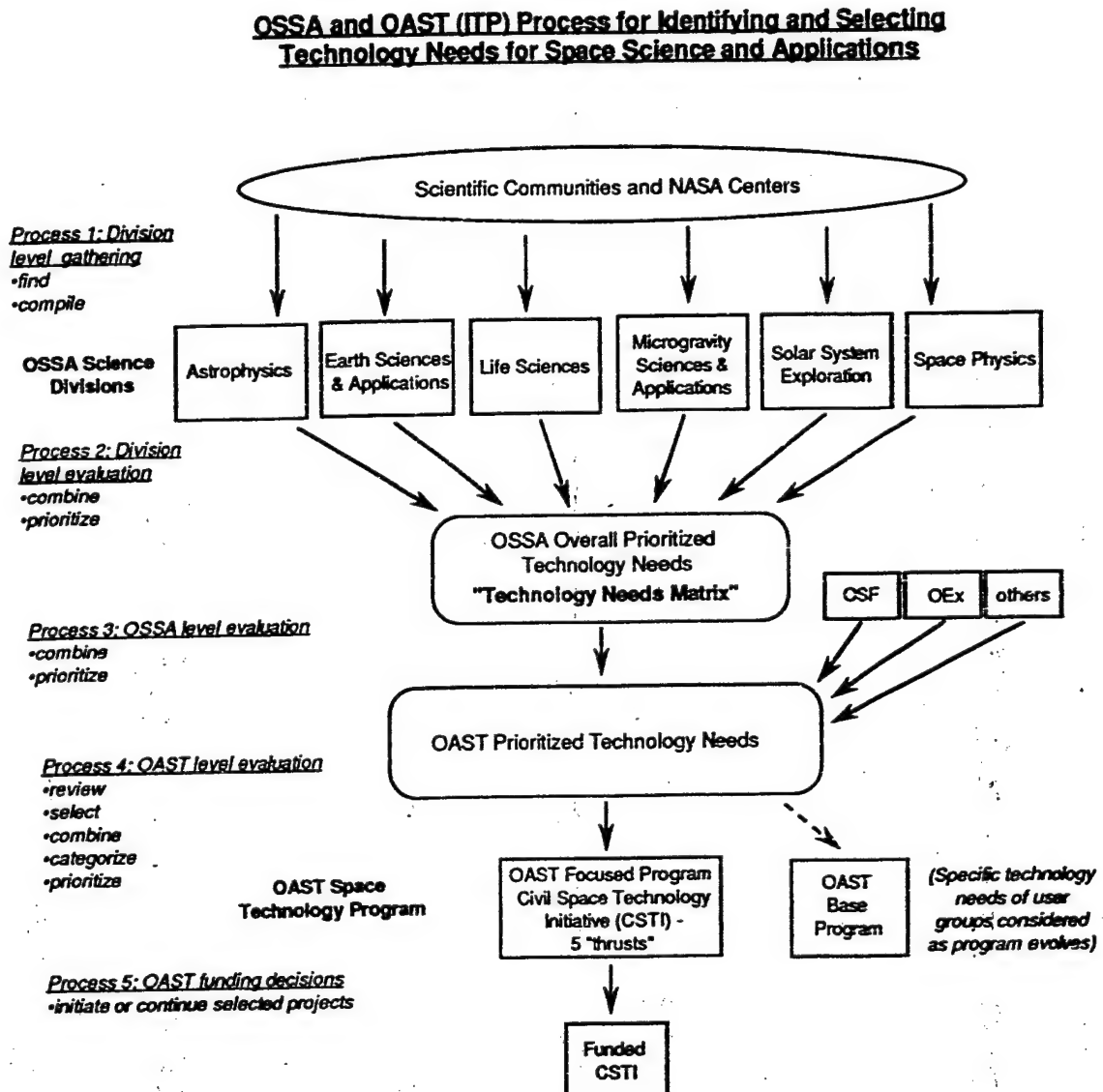
### THE INTEGRATED TECHNOLOGY PLAN

In response to a recommendation by the Advisory Committee on the Future of the U.S. Space Program,<sup>3</sup> OAST prepared the *Integrated Technology Plan for the Civil Space Program* (ITP). The ITP is to:

...serve as a strategic plan for the [OAST] space research and technology (R&T) program, and as a strategic planning framework for other NASA and national participants in advocating and conducting technology developments that support future U.S. civil space missions.<sup>4</sup>



The preparation of the ITP was a major effort that addressed the technology needs of all areas of the NASA space program, other interested government agencies, the commercial space industry, and recommendations of advisory groups. A diagram depicting the flow of space science technology needs through OSSA and OAST, and consistent with the activities taking place during the development of the ITP, is shown in Figure 2. The ITP and its



**Figure 2** The flow of space science technology needs through OSSA and OAST.

## **INTRODUCTION**

**II**

subsequent review by the NASA Space Systems and Technology Advisory Committee (SSTAC) were the final major elements leading to the current study.

A number of important reports over the last decade have served as background for this study. Appendix D contains summaries of the past recommendations made by several advisory bodies that relate to technology for space science and applications. These form the backdrop and in many cases the rationale for OAST's current program and plans. These studies were the point of departure for the development of the OAST Integrated Technology Plan and its subsequent review by the NASA Space Systems and Technology Advisory Committee.

## **NOTES**

1. OAST presentation
2. OSSA 1991 Strategic Plan, p 6
3. Report of the Advisory Committee on the Future of the U.S. Space Program
4. Integrated Technology Plan, p ii

## SPACE SCIENCE AND THE INTEGRATED TECHNOLOGY PLAN

### BACKGROUND INFORMATION

The NASA space science and applications program is described in Table 1, an encompassing statement of its scientific objectives. OSSA's focus is on research objectives, rather than the technology that may be required to meet the objectives. The six program objectives correspond loosely to the principal goals of the science divisions that are part of the Office of Space Science and Applications (OSSA): Astrophysics, Solar System Exploration, Space Physics, Earth Sciences and Applications, Life Sciences, and Microgravity Sciences and Applications. The Life Sciences Division contributes to both of the final two objectives.

Table 1

#### OSSA'S STATEMENT OF OBJECTIVES

- Observe the universe with high sensitivity and resolution across the entire electromagnetic spectrum by completing the Great Observatories Program and conducting selected complementary measurements.
- Complete the detailed scientific characterization of virtually all of the solar system, including the terrestrial planets, typical primitive bodies (asteroids and comets), and the solar system. Develop the scientific foundation to support the planning of human exploration beyond Earth by determining the nature of the environment and surfaces of the Moon and Mars. Search for planetary systems around other stars.
- Quantitatively describe the physical behavior of the Sun, the origins of solar variability, the geospace environment, and the effects of solar processes on the Earth, and extend these descriptions to Sun/planet interactions, to the edge of the heliosphere, and into the interstellar medium and galaxy beyond.

*continued*

(Table 1 continued)

- Establish a set of Earth-orbiting satellites and complementary instruments to study the Earth system on a global scale, examine the planet for evidence of global change, and eventually develop the capability to model the Earth system to predict changes that will occur, either naturally or as a result of human activity. OSSA's efforts constitute a major contribution to the U.S. Global Change Research Program.
- Conduct and coordinate all aerospace medicine, medical support, and life support activities within NASA. Determine human health, well-being, and performance needs, and conduct research, both on Earth and in space, to establish medical and life-support technology requirements for those needs for human flight missions.
- Study the nature of physical, chemical, and biological processes in a low-gravity environment, and apply these studies to advance science and applications in such fields as fluid physics, materials science, combustion science, gravitational biology, medicine, and biotechnology by exploiting the unique capabilities provided by the Space Shuttle, Space Station Freedom, and other space-based facilities.

OSSA has applied the set of principles that are given in Table 2 to its pursuit of the above scientific objectives.

Table 2

OSSA'S STATEMENT OF PRINCIPLES

- Constant emphasis on excellence as a measure of scientific leadership
- Basic scientific goals and strategies defined by the scientific community
- Use of scientific peer review in all aspects of the program
- Balance among the various scientific disciplines
- Close communication with external scientific and applications communities, particularly through the advisory process
- Strong support for universities to provide essential long-term research talents
- Effective use of the NASA centers in formulating and implementing the OSSA program
- Choice of an appropriate mission approach determined by scientific and applications requirements
- Attention to nurturing and enhancing educational opportunities, at all levels, to serve national needs consistent with OSSA's overall goals and missions.

Of particular importance is OSSA's declaration that it will use "scientific peer review in all aspects of the program." In a recent Office of Technology Assessment report<sup>1</sup> peer review was defined as follows:

"Peer review" describes a family of methods used to make funding decisions about research projects. It usually comprises a multistaged process, where reviews of the proposal are solicited from experts in the scientific subdiscipline of the proposal.

Reviewers are most often asked about the technical excellence of the proposal, the competence of the researchers, and the potential impact of the proposed project results on a scientific discipline or interdisciplinary research area. Peers may also be asked about the project's relevance to the objectives of the funding program. The proposals and reviews may then be considered by a panel of experts, and competing proposals compared. The panel eventually ranks the proposals in the order in which they think the proposed projects should be funded.

Peer review is not unique to the funding of research at academic institutions. The same principles of external, peer scrutiny can be applied to the selection of tasks to be carried out in a federal laboratory or industrial firm.

OSSA has a clear intent to employ peer review to guide its programs. In OSSA, the external community helps choose programs and experiments and contributes to their execution. Advisory panels help OSSA rank missions and sharpen its decision processes. The extent to which peer review is incorporated into the processes by which OSSA identifies technology needs and develops technology is less clear. Rigorous peer reviews are employed to select scientific experimenters and instruments, and strong pressure is placed on the publication of results in peer-reviewed journals. The quality of the scientific results profoundly affects whether a mission is perceived as a success.

OSSA's strategy is based on the principles in Table 2 and developed through the five actions shown in Table 3.

Table 3

OSSA'S STRATEGIC ACTIONS

1. Establish a set of structural elements.
2. Establish a set of decision rules.
3. Establish a set of priorities for missions and programs within each structural element.
4. Demonstrate that the strategy can yield a viable program.
5. Check the strategy for technology readiness and for consistency with resource constraints, such as budget, manpower, facilities, and launch vehicle availability.

The last of these actions, checking the strategy for technology readiness and consistency with resource constraints, raises the issue of whether or not technology is available to perform the missions linked to OSSA's strategy.

The decision rules that OSSA applies to its program are listed in Table 4. The theme of technology readiness is reinforced in the last of these decision rules, which calls for an investment to develop needed technologies.

Table 4

## OSSA DECISION RULES

1. Complete the ongoing program.
2. Provide frequent access to space for each discipline through new and expanded programs of small innovative missions.
3. Initiate a mix of intermediate/moderate profile missions to ensure a continuous and balanced stream of scientific results.
4. Initiate flagship missions that provide scientific leadership and have broad public appeal.
5. Invest in the future by increasing the research base to improve program vitality and by developing needed future technologies.

Through the above processes, OSSA develops its desired strategy, makes initial plans for programs and, in principle, derives a point of departure from which its divisions determine their sets of required technologies.

#### OSSA Criteria for the Evaluation of Technology Needs

Technology development projects at OSSA are individually selected and undertaken by its divisions; there is no overarching OSSA technology development program. Estimates by the divisions of their FY 1992 expenditures in support of technology development are provided later in this chapter and compiled in Appendix C.

In responding to OAST's request for information about OSSA technology needs as part of the ITP preparation process, OSSA consolidated the technology needs of its six science divisions into a single set. In doing so, OSSA reviewed the inputs from each division, combined similar inputs from different divisions into single need categories, and ranked these technology needs in three categories ("highest," "second highest," and "third highest") within three time frames ("near-term," "mid-term," and "far-term"). The resulting matrices are presented in Appendix E.

The criteria used during the OSSA consolidation and prioritization process were as follows:

- "Mission Urgency" (how necessary is the technology for an existing mission);
- "Commonality of Technology Requirements" (the prevalence of the need among divisions);
- "Balance Across Disciplines and Subdisciplines" (fairness in distribution of requests for technology initiatives); and
- "Relevance to Strategic Plan" (the Strategic Plan is OSSA's planning document).

The technology needs criteria to be used by each division in the preparation of their input to OSSA were as follows:

- "Commitment to Ongoing Program" (can existing programs benefit from this technology development);
- "Urgency of Mission/Experiment" (how necessary is the technology for a specific mission);
- "Understanding of Requirement" (is the need sufficiently defined to permit a sound development project);
- "Technology Maturity" (is technology sufficiently mature for adoption with reasonable risk);
- "Projected Cost Reduction;"
- "Commonality Across Division Instruments, Systems, Subsystems" (how widespread is the need in the division).

These criteria are, in some cases, different from those in the processes described by the science divisions in the next section of this chapter.

### OSSA Divisions and Technology Development

The Committee found no evidence of the existence of an OSSA-wide advanced technology strategy or plan prior to the activities leading to the ITP. Ad hoc processes appear to be followed. The procedures employed by the science divisions to choose technological development targets lack uniformity and, in some cases, rigor. The ITP required an OSSA-level ranking of technology needs. This activity was performed for OAST, rather than for OSSA internal planning.

Information on OSSA's FY 1992 budget is provided in Table 5. The combined technology development expenditures of OSSA's divisions are small (estimated by OSSA at about \$48.8 million for FY 1992) in comparison to OSSA's overall budget (\$2.728 billion for FY 1992), and equal to about 40 percent of OAST's estimate of its expenditure relevant to OSSA's technology needs. NASA estimates the total OSSA technology budget and the portion of the OAST's budget relevant to space science to be as much as \$177 million (see Appendix C). Whether NASA's current expenditure is adequate to reduce the development risk of the OSSA missions is an open question that is addressed in the last chapter of this report.

The following four sections—covering Astrophysics and Space Physics, Earth and Planetary Sciences, Life Sciences, and Microgravity Science and Applications—are based on the work of the Committee's four subcommittees. They provide background information on each of OSSA's science divisions, discuss the processes by which technology needs were determined by each division, and present relevant findings and recommendations.

Table 5 FY 1992 Budgets of the OSSA Science Divisions, their Research and Analysis Budget and Estimated Technology Development Expenditures

OSSA Division	Division Budget (\$ million)	Research and Analysis Budget (\$ million)	Technology Development Expenditure (\$ million)
Astrophysics	683.7	35.5	$\geq 11.3$
Earth Science and Applications	747.5	175.1	$\leq 10$
Life Sciences	148.9	50.7	$\leq 5$
Microgravity Science and Applications	120.8	16.6	$\sim 8$
Solar System Exploration	534.5	90.7	$\leq 5.5$
Space Physics	275.6	35.0	$\leq 3.5$

Source: NASA



## THE ASTROPHYSICS AND SPACE PHYSICS DIVISIONS

There is a strong interdependence between science and technology. Scientific advances frequently enable new technologies while new technology is often the basis for scientific discoveries. Over the past three decades initial exploratory missions have been followed by more sophisticated investigations and have yielded a new view of a dynamic Sun, giant planetary magnetospheres, and an extended heliosphere, all driven by complex plasma processes. Observations in the electromagnetic spectrum from low-frequency radio to high-energy gamma rays led to the awareness of a universe far more dynamic than previously thought. Background radiation from the beginning of the universe has challenged pre-existing theories. Understanding newly discovered processes and phenomena, within our solar system and on a galactic scale, will require classes of observation beyond our present capabilities. The dependence of astrophysics and space physics on new technologies is likely to grow.

### Background: Astrophysics Division

The Astrophysics Division has the goal to "conduct a comprehensive exploration of the universe." The themes of its research in astronomy—"What is the nature of planets, stars and galaxies?"; cosmology—"What is the origin and fate of the Universe?"; and physics—"What are the laws of physics in the extreme conditions of astrophysical objects?", encompass profound questions that have been of interest to human beings for millennia.

Research sponsored by the division is performed through the use of a variety of robotic or automated spacecraft in Earth orbit above the filtering and scattering effects of the atmosphere. Recently, its emphasis has been on the "Great Observatories," four Earth-orbiting satellites. The Compton Gamma Ray Observatory (GRO), the Advanced X-Ray Astrophysics Facility (AXAF), the Hubble Space Telescope (HST), and the Space Infrared Telescope Facility (SIRTF) are designed to study astronomical objects by gathering data throughout a wide portion of the electromagnetic spectrum. The Astrophysics Division has identified technology needs in five major areas: sensors, optics, interferometers, observatory systems, and information systems. The Astrophysics Division has an Advanced Programs Branch containing an Advanced Technology Program, and estimates its FY 1992 expenditures in support of technology development at \$11.3 million.

### Technology Needs Compilation and Evaluation

The process by which the Astrophysics Division determines its technology needs is highly developed, institutionalized, and intimately tied to its Astrotech 21 Program.

The Astrotech 21 Program, initiated by the Astrophysics Division in 1989 and managed by the Jet Propulsion Laboratory (JPL), is a major effort involving hundreds of active scientists and engineers from all constituent groups of the astrophysics community. It is aimed at identifying the technology needs of future astrophysics missions. The results of the Astrotech 21 Program have been reviewed by the scientific discipline advisory groups and science working groups. More specifically, the Astrotech 21 Program has conducted a series of workshops to:

- Define science goals and objectives.
- Develop "point design" mission concepts.
- Identify technology development needs.
- Develop technology development plans to meet those needs.
- Develop technology development priorities.
- Develop technology development plans for each future mission and for each subdiscipline.

Priorities for technology development within the Astrophysics Division are based on the following criteria, in order of importance:

- Urgency—When is the technology needed?
- Criticality—Is the technology enabling or enhancing the mission?
- Difficulty—How much effort is required compared to the state of the art?

#### **Background: Space Physics Division**

Space Physics encompasses the study of the Sun, interplanetary space, the magnetospheres and upper atmospheres of planets, and interstellar space. The goals of the Space Physics Division are to pursue the study of the heliosphere as one system, and achieve an understanding of the physics of:

- The Sun and the solar wind, and their interactions with the upper atmospheres, ionospheres, and magnetospheres of the planets and comets; energetic particles; and the interstellar medium.
- The effects of energetic particles and solar variability upon the Earth's environment, and human operations in space.

Space Physics missions use orbiting spacecraft and spacecraft on interplanetary missions to gather data from different regions within the solar system (heliosphere). The Space Physics Division has an Advanced Programs Branch and estimates its FY 1992 expenditures in support of technology development at \$3.5 million. These funds are primarily spent at or through NASA field centers to advance approved space physics missions.

#### **Technology Needs Compilation and Evaluation**

In 1991 the Space Physics Division conducted a workshop to identify its technology needs. This workshop was attended primarily by NASA field center and aerospace industry representatives. Its results, published in July 1991, defined the division's technology needs. Some modifications have since been made, but without broad community concurrence or a rigorous review such as the Astrophysics Division's Astrotech 21 Program. The division's decision rules to develop its technology needs are:

- "Urgency—Does project provide essential or significant benefits to a core science mission or experiment?"
- "Commonality—Is it applicable to multiple missions, instruments, and systems?"
- "Cost—Will it result in significant project cost reduction?"
- "Timing—Can it be planned and implemented in an acceptable time frame?"

### FINDINGS

- While there does appear to be a strong ongoing program in the development of infrared and submillimeter detectors, there are critical gaps in the OSSA technology needs plan and matrix for astrophysics and space physics which are, to some extent, generic. These gaps are: 1) the need for technology development to design, build, launch, and operate spacecraft for astrophysics and space physics research in a faster and less costly manner; 2) the need to develop a large range of radiation-hardened electronic components and subsystems; and 3) the need to support a broad spectrum of smaller innovative technology developments in photon and non-photon sensors as well as other subsystems.
- The Committee could find few instances of transferring technology from other NASA developers or from the OAST Base Program to astrophysics or space physics programs. One of OAST's critical functions is to develop non-mission-specific advanced space technology in its Base Program. The base technology program is managed and its objectives set as an internal NASA program. Opportunities for introducing important novel initiatives from outside NASA are limited, even though the funding itself may go to outside communities.
- Although OAST has estimated that it spends 12 percent of its space technology budget at universities, only about \$15 million (five percent) is specifically targeted to bring external academic expertise into OAST through its "University Space Engineering Research Centers" and "University Research Programs." The vast technical resources of the nation's universities and other research organizations could make a greater contribution to NASA's technical capabilities, including those related to astrophysics and space physics, if they were supported to a greater extent by OAST's space technology program.

**RECOMMENDATIONS**

- **NASA should continue to work to improve cooperation between OSSA and OAST in technology for astrophysics and space physics. This might take the form of a formal partnership to identify goals, objectives, and a clear path to transfer technology from the OAST base and focused programs to OSSA. OSSA should continue to use its resources on near-term programs, and OAST should continue to concentrate on long-range technology needs. However, both parties should specifically agree on the points at which technology development projects will be transferred from OAST to OSSA.**
- **The OAST R&T base program and its individual projects in support of space science should be subjected to more visible external review on a regular basis. OSSA representatives should be included in the review team. This could contribute to a sense of "ownership" of the OAST base technology program in those it aims to serve and facilitate the ultimate transfer of new technology to users.**
- **The technology gaps addressed above should be added to the OSSA technology needs matrix. The Committee also recommends technology development projects to foster a broad range of innovative capabilities for smaller missions.**

## THE EARTH SCIENCE AND APPLICATIONS AND SOLAR SYSTEM EXPLORATION DIVISIONS

### Background: Earth Science and Applications Division

The place of the Earth Science and Applications Division in OSSA is unique. Its goal, "to establish the scientific basis for national and international policymaking relating to natural and human-induced changes in the global Earth system," is of a different nature than any of the other divisions. It does not by definition specify research inherently related to space or space flight. However, its objectives are analogous to the goals of the other divisions. Its objectives are to:

1. Establish an integrated, comprehensive, and sustained program to document the Earth system on a global scale;
2. Conduct a program of focused and exploratory studies to improve understanding of the physical, chemical, biological, and social processes that influence Earth system changes and trends on global and regional scales; and
3. Develop integrated, conceptual, and predictive Earth system models on global and regional scales.<sup>2</sup>

The Earth Science and Applications Division has its own mandate as part of the U.S. Global Change Research Program (an integrated effort by 11 U.S. government agencies). It is also part of the international effort to study the climate and environmental conditions of the Earth by the space and other scientific agencies of more than a dozen nations. As such, its technology requirements are not derived from a small community of researchers or based on the needs of purely scientific research projects, but stem from national and international policy concerns. The technology needs of the division are associated with enabling programs that use geostationary satellites, earth probes, polar orbiting satellites, low-inclination orbiting satellites, aircraft, balloons, etc., to sense a variety of parameters. Phenomena in the Earth's atmosphere, oceans, land masses, and biosphere are studied and analyzed with an eye towards enabling the development of algorithms for modeling critical aspects of the Earth.<sup>3</sup>

The Earth Science and Applications Division's strategy is described as follows:

"The long-term strategy for the Earth Science and Applications Division has been defined by the Earth System Science Committee and the subsequent definition of the U.S. Global Change Research Program by the interagency Committee on Earth and Environmental Science to focus on three objectives: 1. establish an integrated, comprehensive monitoring program for Earth system measurements on a global scale; 2. conduct a program of focused studies to improve our understanding of the physical, chemical, and biological processes that influence Earth system changes and trends on global and regional scales; and 3. develop integrated conceptual and predictive Earth system models."<sup>4</sup>

The Mission to Planet Earth and the Earth Observing System (EOS) have been established to address the first objective.

The division contributed nine technology needs to the final OSSA technology needs matrix presented to OAST. No clear description was given to the Committee showing the process the division used to determine its technology needs. The Earth Science and Applications Division does not have a specific advanced technology development branch or program; it has estimated \$10.0 million as its FY 1992 spending on technology development.

### **Background: Solar System Exploration Division**

The Solar System Exploration Division has stated that its goals and approaches are derived from and consistent with those recommended by the Committee on Planetary and Lunar Exploration of the National Academy of Sciences and the Solar System Exploration Committee of the NASA Advisory Council.<sup>5</sup> They are:

#### **Solar System Origins**

- Understand the process of solar system formation, in particular planetary formation, and the physical and chemical evolution of protoplanetary systems.

#### **Planetary Evolution and State**

- Obtain an in-depth understanding of the planetary bodies in our solar system and their evolution over the age of the solar system.

#### **Evidence of Life**

- Search for evidence of life in our own and other planetary systems, and understand the origin and evolution of life on Earth and other planets.

#### **Robotic and Human Exploration**

- Conduct scientific exploration of the Moon and Mars, and utilize the Moon as a base of scientific study in participation with NASA's Mission from Planet Earth.

Solar system exploration is conducted in three distinct stages: 1. reconnaissance, involving flyby missions; 2. exploration, generally conducted with orbiting spacecraft, hard landers, and atmospheric probes; and 3. intensive study, involving soft landers, sample returns, and human exploration. The essential part of this exploration is a core science program of balanced missions and research that stresses continuity, commonality, cost-effectiveness, and the use of existing technology. Future programs envision completing the reconnaissance phase for all planets, completing the exploration phase of the inner solar system and small bodies, advancing the exploration phase of the outer planets, and conducting in-depth studies of Mars and a comet or asteroid.<sup>6</sup>

### Technology Need Compilation and Evaluation

The Solar System Exploration Division's technology planning strategy is as follows:

- Step 1: Derive a set of technology themes consistent with the division's (and OSSA's) strategic perspective.
- Step 2: Identify a set of decision rules and a process for eliciting technology needs and priorities.
- Step 3: Identify and synthesize the division's technology needs.
- Step 4: Establish the priorities.
- Step 5: Integrate needs and priorities with OAST, iterating as necessary.
- Step 6: Continue to evolve understanding of technology requirements and update plans to reflect advancements/setback and programmatic exigencies.
- Step 7: Implement and coordinate technology plans with OAST, the Solar System Exploration Division, and supporting organizations.

According to the division's representative, the process was initially informal, and implemented primarily at the headquarters level, but the planetary community has now become aware of, and committed to, these planning principles.

The Solar System Exploration Division contributed 21 technology needs to the final OSSA technology needs matrix presented to OAST. The Solar System Exploration Division has an Advanced Studies Branch and estimates its FY 1992 expenditures in support of technology development at \$5.5 million.

### FINDINGS

- The technology needs submitted by the Earth Sciences and Applications Division and the Solar System Exploration Division for inclusion in the ITP do not reflect their respective communities' need for increased access to space through smaller, quicker, more flexible, and less expensive missions. For example, the Solar System Exploration Division has shifted its emphasis from a few big missions to more frequent access to space and more flexible missions. This shift was not reflected in the ITP or the OAST briefings to the Committee. Similarly, the Earth Sciences and Applications Division recently modified its EOS program and does not appear to have requested help from OAST regarding its shift in paradigm from large to smaller spacecraft.
- The Committee believes that an effective discussion has occurred between OAST and the Earth Science and Applications and Solar System Exploration Divisions in developing the current ITP, but it is not clear that the divisions have requested technological assistance with their most basic problems. With respect to the earth and planetary sciences, the weaknesses in the ITP lie in what is not there rather than what is. The Earth Sciences and Applications Division's submission to OAST of only nine technology needs does not correspond to its significant technology-dependent



responsibilities. For example, the division has not identified technologies to support orbital debris mitigation or very high altitude observations as needs. The Solar System Exploration Division has not identified *in situ* resource utilization despite its potential to reduce the cost of large-scale planetary exploration.

- Avoidance of risk at NASA has been elevated to such a position that innovation in the development of technology for earth and planetary sciences has suffered. For the last decade or longer, programs in these areas have generally been very expensive and very large, and only initiated after years of deliberations. NASA's culture, organization, and past experiences seem to have made the establishment of new ways of doing business very difficult. Studies and program plans seem to have flourished at the expense of scientific innovation, innovative technology development, and actual projects. The preparation of the ITP appears to have started a wholesome process to correct these problems, but efforts need to continue.
- While the Committee was often reminded that OSSA and OAST managers were determined to communicate to ensure an effective development process, there was little actual evidence of science users in earth and planetary sciences and technology developers teaming to produce a tangible result.

#### RECOMMENDATIONS

- NASA's Earth Sciences and Applications and Solar System Exploration Divisions should act to increase their programs' vitality through the development of less expensive platforms for Earth observation and planetary probes, e.g., micro- and mini-satellites, and remote-controlled aircraft for sustained access to very high altitudes. Long-term needs in this area should appear in both lists of technology needs.
- The objective of easier access to space should be explicit in OSSA's inputs to OAST, and in the formulation of technology development projects at each office.
- As both divisions improve their programs through the use of new or improved technologies, emphasis should be placed on technologies with the potential to reduce end-to-end mission costs, as savings in the real costs of programs can contribute to more frequent and less complicated access to space.
- OSSA and OAST should act to improve communication between the Earth Sciences and Applications Division, the Solar System Exploration Division, both division's scientific communities, and those able to contribute to the development of their technology needs. OSSA and OAST should emphasize a team approach to problem solving both at NASA headquarters and where the work actually takes place, including NASA centers.



### THE LIFE SCIENCES DIVISION

The goals of the Life Sciences Division are to "ensure the health, safety, and productivity of humans in space" and to "acquire fundamental scientific knowledge concerning space biological sciences." The division aims to "expand our understanding of life in the universe; develop an understanding of the role of gravity on living systems; provide for the health and productivity of humans in space; and promote the application of life sciences research to improve the quality of life on Earth".<sup>7</sup> The Committee considered the division's goals and programs and identified the following scientific constituencies covering the division's research areas: life support, integrative physiology, operational medicine, space biology, human/systems interaction, and exobiology.

Since 1981, the Life Sciences Division has carried out the bulk of its space-based research on the Space Shuttle. The division's experiments are generally conducted using biomedical devices or animal, plant, or cell maintenance or growth facilities that are specially designed or specially modified for space flight and integrated into the Shuttle mid-deck or the Spacelab module. Devices used in space life sciences research require various levels of crew interaction. Some need little or no crew contact during nominal performance, while others are literally connected to the crew, monitoring and recording physiological functions. Most space life sciences hardware is used in the pressurized volume of the Shuttle and must meet stringent safety and other requirements (e.g., noise). Technologies related to exobiology, which includes the search for life or its precursors outside of Earth and the study of the effects of extraterrestrial environments on living organisms, have different standards because they can be employed on robotic spacecraft or other sites not in direct contact with crewmembers.

The space life sciences research community is small in comparison to the overall biological and biomedical research communities and has depended on proven technologies to a large extent. A widespread need of this community is to be able to adapt off-the-shelf laboratory technology quickly and safely for use in space. The kinds of technology needed for biomedical experiments in space are generally readily available for similar studies on Earth. The primary difficulties of conducting research in space have been associated with the difficulty of qualifying hardware for space flight and the paucity of space flight opportunities. Operational or technology problems related to low-gravity, or other inherently space-related phenomena, have been secondary to organizational, programmatic, logistical, and other non-scientific constraints to research. These deficiencies have constrained the space life science as a discipline. The flight hardware available for space flight has driven scientific research rather than the reverse. The absence of adequate technology and flight opportunities has led to an overabundance of descriptive and anecdotal observations of astronauts' physiological responses to microgravity instead of peer-reviewed research results. Important hypotheses have not been fully tested and mechanisms partially revealed have not been explored. As a result, the biomedical community has not fully accepted the discipline.

The Space Shuttle missions on which life sciences research has taken place have primarily been dedicated to other purposes although one mission wholly dedicated to life sciences, and a few having life sciences as a major emphasis, have been flown. Several wholly or partially dedicated missions are planned for the remainder of the 1990s. Space Station Freedom is considered the primary future site for life sciences research in space.

The division has estimated its FY 1992 expenditure for technology development at \$5 million. The Life Sciences Division does not have a dedicated advanced technology development program.

### Technology Need Compilation and Evaluation

The processes associated with the identification and evaluation of the Life Sciences Division technology needs begin with the division requesting that its affiliated project offices at NASA field centers (Johnson Space Center, Ames Research Center, and Kennedy Space Center) and flight programs and science branches at NASA headquarters identify and forward technology need requirements and candidates.<sup>8</sup> Cost estimates for candidate technology needs are requested.

Candidate technology needs are categorized and ranked by the Life Sciences Division Technology Coordinator, who puts each technology need into one of three priority levels based on the program or mission enabled, synergy with Life Sciences Division objectives, and cost.

Before they are forwarded to OSSA, the technology needs are reviewed and approved by division management, which ensures that they are aligned with Life Sciences Division objectives and its strategic plan. Once approved, technology needs are forwarded to OSSA for incorporation into its technology needs matrix.

In the 1992 process, the Life Sciences Division contributed 25 technology needs to the OSSA technology needs matrix presented to OAST.

### FINDINGS

- The division has not adequately included the prospective users of new technologies in the scientific community (both internal and external) for the space life sciences into its technology need gathering and evaluation processes.
- The division has placed little emphasis on determining its *bona fide* technology needs, and there is little correlation between the division's strategic plan and the technology needs submitted to OSSA and forwarded to OAST. The current life sciences technology needs contained in the OSSA technology needs matrix are not, as a group, matched to recognized plans or clear priorities. The relevant categories in the OSSA matrix, and the inputs from the Division to the matrix, are often vague or confused to the point that some items in the matrix defy evaluation or quantitative assessment.
- The Committee considers it premature to diagnose the gaps between the OAST program and the OSSA inputs to OAST because the Life Sciences Division inputs to OSSA, as a group, have limited legitimacy.

**RECOMMENDATIONS**

The Life Sciences Division should do the following:

- Create a division plan for technology that is integrated with its strategic plan, consistent with its programs, and approved by its director.
- Empower its scientific discipline working groups to identify technology needs and to review recommendations from other sources. The division should take special efforts to ensure that discipline working group membership includes scientists with recent experience in the development of complex flight experiments.
- Cooperate more closely with OAST on projects relevant to the division's mission.
- Revise its decision rules and criteria to permit objective and consistent evaluation of technology needs.
- Rank technology needs using critical path analyses, i.e., plan the development of technologies for a particular scientific area mindful of the sequence in which they are projected to be needed. Address basic questions before esoteric ones.
- Formalize technology planning responsibilities to identify, coordinate, and report relevant work within the division.

### THE MICROGRAVITY SCIENCE AND APPLICATIONS DIVISION

The low-gravity environments aboard orbiting spacecraft and on some extraterrestrial bodies offer unique conditions for scientific inquiry and also present challenging problems and opportunities for the development of mission-enabling technologies. In the following circumstances, the role of gravity in physical phenomena is uniquely important:

1. As a driving force for convection in fluids;
2. As a driving force for phase separation;
3. As a force that helps to determine the free surface morphology of fluids;
4. Near a critical point;
5. In the presence of very weak binding forces;
6. In the presence of very large masses or for very long times; and
7. In structural members or over very long distances.

To date, most microgravity experiments have been focused on exploring the first two circumstances above. These experiments have included studies of crystal growth in fluids, fundamental phenomena in crystal growth, convection phenomena, measurement of the transport properties of fluids, combustion phenomena, fire safety aboard spacecraft, and immiscible alloys and multiphase solids.<sup>9</sup>

The goals of the Microgravity Sciences and Applications Division are to

1. Develop a comprehensive research program in biotechnology, combustion, fluid dynamics and transport phenomena, materials science, and selected investigations of other gravity-dependent phenomena;
2. Foster the growth of an interdisciplinary community to conduct the research and to disseminate the results;
3. Enable the research by the development of a suitable experiment apparatus and by choosing the carrier most appropriate for the experiment;
4. Promote U.S. commercial involvement and investment in the application of space research for the development of new, commercially viable products, services, and markets resulting from research in the space environment;
5. Foster international cooperation and coordination in conducting low-gravity research of mutual benefit, while maintaining the United States' competitive commercial position.<sup>10</sup>

The division's goals involve pure science, and the development of technology for science, but are also operations-oriented. Research into combustion and other processes occurring in microgravity are of interest for their potential effects on future spacecraft, flight hardware, and crew safety and operations, as well as for the purely scientific insights and the potential earth applications they may generate. Goals 4 and 5 are distinct due to their national policy implications.

Microgravity research involves diverse disciplines and is in the process of developing a distinct scientific community. In 1991 the division, recognizing this situation, requested that the Space Studies Board's Committee on Microgravity Research perform a study to help develop its long-term research strategy. The SSB recently published a report based on a review initiated in 1989 to this end. Entitled *Towards a Microgravity Research Strategy*, it is currently being assessed by the division.

Most Microgravity Science and Applications Division space-based research is currently performed using the Space Shuttle mid-deck and Spacelab module. But unlike the Life Sciences Division, which also uses these resources, experiments in a number of scientific areas of interest to the division can be performed on orbiting unmanned spacecraft. Such spacecraft could be man-tended, i.e., occasionally visited by astronauts who would retrieve samples and initiate additional experiments. The division performs experiments requiring shorter durations in low-gravity conditions (up to a few minutes) through the use of suborbital rockets with automated, retrievable payloads. To date, one Space Shuttle mission entirely dedicated to microgravity sciences and a few with the microgravity sciences as a major emphasis have been conducted. Several wholly or partially dedicated missions are planned for the remainder of the 1990s. The Life Sciences and Microgravity Sciences and Applications Divisions are expected to be NASA's primary scientific users of Space Station Freedom's pressurized volume.

The Microgravity Science and Applications Division contributed 11 technology needs to the final OSSA technology matrix presented to OAST. The division has a distinct Advanced Programs Branch and Advanced Technology Development Program and estimates its FY 1992 expenditures in support of technology development at \$8.0 million. The projects funded by the Advanced Technology Development Program are limited to origination at NASA centers and annual funding of under \$200,000 each; provisions exist to involve academia and industry. Projects sponsored by the program are not to be on the critical path of any flight project. In FY 1992, the program funded 11 projects at JPL, the Langley Research Center, the Lewis Research Center, and the Marshall Space Flight Center.

#### **Technology Need Compilation and Evaluation**

The Microgravity Sciences and Applications Division has identified a six-step technology needs compilation and evaluation process. In step one, candidate technologies are selected from prior reports and inputs are sought from a survey of division program and project scientists and engineers at NASA centers and headquarters. In step two, candidate technologies are organized into a decision matrix according to science discipline, facility or experiment, mission or carrier, and projected flight date. In step three, the candidate technology needs are scored on the Microgravity Sciences and Applications Division technology need scale, which has five levels: A - Must have to succeed; B - Important, but not critical for success; C - Would use if available (enables new experiments); D - Mildly interested in using technology; and E - No interest or not applicable.

In step four, the technology needs are reviewed by division program and project scientists and engineers at NASA centers and headquarters. Reviewers who fill out a decision matrix and some inputs are sought from experiment principal investigators. In step

five, the technology needs evaluation scores are compiled and given a final review by division personnel. After review, a summary technology needs matrix is submitted to OSSA for integration into the OSSA Technology Needs Matrix.<sup>11</sup>

### FINDINGS

- The ITP process has fostered communication between OAST and the OSSA Microgravity Sciences and Applications Division.
- Although opinions may differ on specific priorities and microgravity research technology needs identified in the OSSA technology needs matrix, the items listed are significant and merit attention.
- OAST does not have a history of developing technologies for the microgravity sciences, and there is no OAST constituency in microgravity. OSSA projects at the Lewis Research Center and Marshall Space Flight Center seem disconnected from OAST.
- Microgravity research has agency-wide relevance. Many physical processes that could be affected by microgravity considerations are important in space-based technologies and relevant to activities throughout NASA. Examples are power systems, thermal management devices and systems, fire hazard management, multiphase flow, cryogenic engines, physical and chemical life support systems, and user support systems such as toilets and refrigerators.<sup>12</sup>
- OAST should also consider the effects on technology exerted by forces other than gravity, perhaps including forces so weak that they are generally considered insignificant. Research into a variety of micro- or nanoforces (e.g., magnetic and electrostatic) that may have significance in orbit, but are negligible in comparison to gravity on the ground, could also enrich the Microgravity Sciences and Applications Division.
- The Microgravity Sciences and Applications Division does not appear to be seeking help from OAST in areas of OAST expertise such as fluid mechanics, heat transfer, and computational fluid dynamics, where OAST/OSSA cooperation might contribute to NASA-wide advances. There is also no indication that OAST has sought out the Microgravity Science and Applications Division's expertise to help advance relevant technology.

## RECOMMENDATIONS

- The recent improvements in the OAST/OSSA interaction in microgravity sciences at NASA headquarters should be enhanced and elevated to the highest levels. Liaison groups, including staff from NASA centers, should be encouraged to identify and focus on crucial, feasible joint projects.
- OAST and the Microgravity Sciences and Applications Division should establish a joint working group in microgravity (with membership drawn from NASA, universities, industry, and government laboratories) to focus on microgravity sciences and space technology. The working group should be charged to consider relevant aspects of the OAST In-Space Technology Experiment Program (IN-STEP) and the possible formulation of a new applied research program for applied microgravity sciences within OAST.
- Microgravity effects should be carefully considered during the development of space technology for OSSA and other NASA offices.
- Many mission-enabling technologies involve transport phenomena which are significantly influenced by the lack of gravity. Therefore, it is essential that advancements in microgravity research be well understood by OAST and that OAST support microgravity research directly related to space technologies.

## NOTES

1. OTA, Federally Funded Research: Decisions for a Decade
2. Division presentation to Committee, June 22, 1992
3. Based on 1991 OSSA Strategic Plan
4. 1991 OSSA Strategic Plan
5. 1991 OSSA Strategic Plan
6. 1991 OSSA Strategic Plan
7. Division June 22, 1992 briefing to Committee
8. Division June 22, 1992 presentation to Committee
9. SSB Committee report: Toward a Microgravity Research Strategy, p 2
10. Division June 23, 1992 presentation to Committee
11. Division June 23, 1992 presentation to Committee
12. Ostrach, Simon. 1992. *White Paper on NASA-Wide Microgravity Research*, p 14



## **SPACE TECHNOLOGY AND THE INTEGRATED TECHNOLOGY PLAN**

### **THE OAST SPACE TECHNOLOGY PROGRAM**

The Office of Aeronautics and Space Technology is divided into several directorates, the two largest of which are responsible for aeronautics and space technology. The mission statement of the Space Technology Directorate is shown in Table 6.

Table 6

#### **OAST'S SPACE RESEARCH AND TECHNOLOGY MISSION STATEMENT -**

OAST shall provide technology for future civil space missions and provide a base of research and technology capabilities to serve all national space goals.

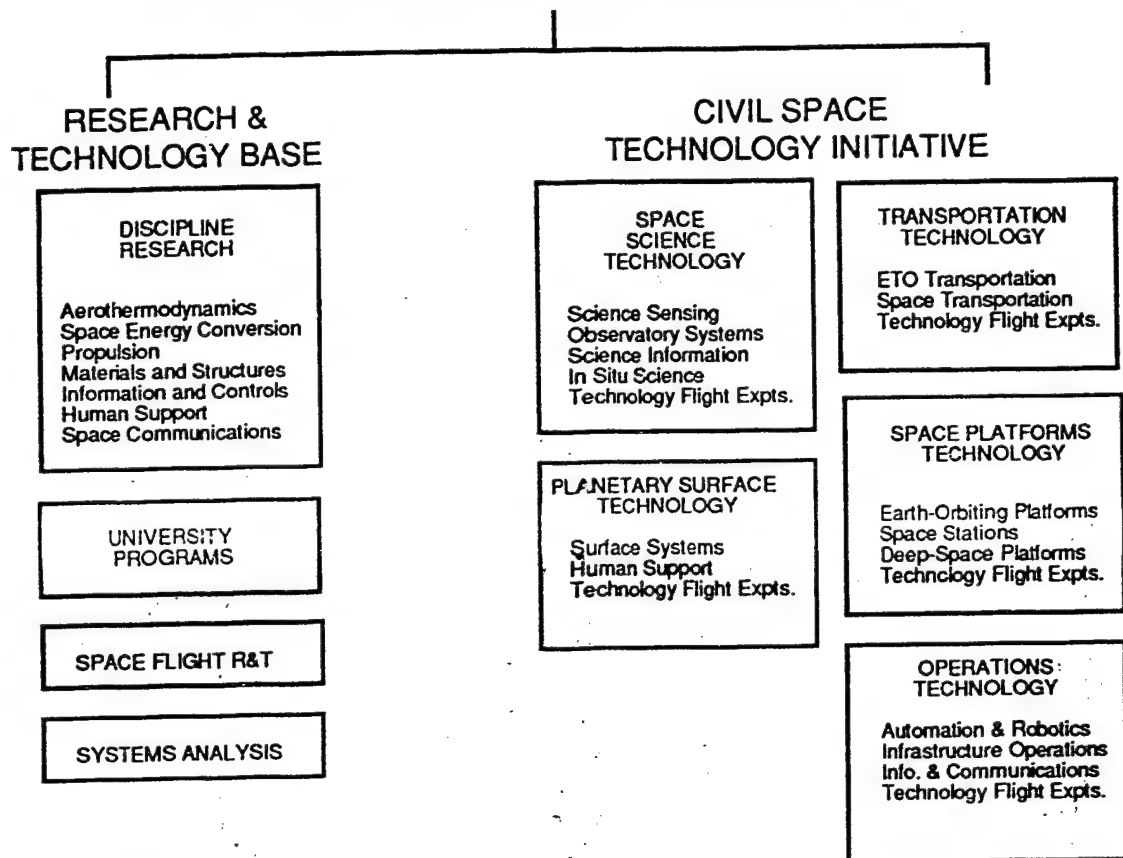
- Identify, develop, validate and transfer technology to:
  - Increase mission safety and reliability
  - Reduce program development and operations cost
  - Enhance mission performance
  - Enable new missions
- Provide the capability to:
  - Advance technology in critical disciplines
  - Respond to unanticipated mission needs

The Space Technology Directorate is organized as shown in Figure 3 to meet two major responsibilities: basic and focused research in support of the nation's civil space program. The Civil Space Technology Initiative constitutes the "focused program" and is of primary interest to this study. It is the part of OAST which has been particularly configured to be responsive to the technology needs of future missions, including the needs of OSSA. The focused program contains five thrusts: space science technology, operations technology, transportation technology,



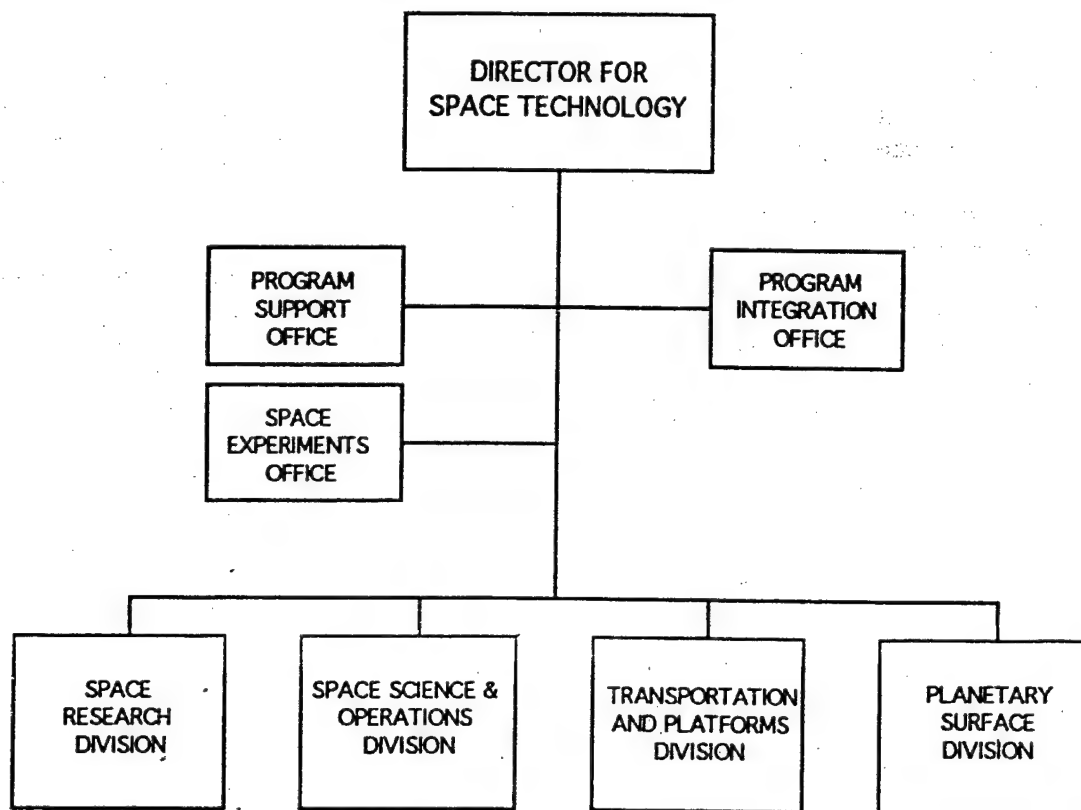
space platforms technology, and planetary surface technology. Figure 4 shows the management structure of the OAST Space Technology Directorate.

## SPACE RESEARCH AND TECHNOLOGY



Source: NASA

**Figure 3** The OAST Space Technology Directorate programs.



### OAST SPACE TECHNOLOGY

Source: NASA

**Figure 4** The OAST Space Technology Directorate management structure.

### THE INTEGRATED TECHNOLOGY PLAN (ITP)

#### The Development of the ITP

As noted earlier, the OAST ITP was developed in response to a recommendation by the Advisory Committee on the Future of the U.S. Space Program.<sup>1</sup> NASA tasked OAST to prepare an integrated technology plan to "serve as a strategic plan for the space research and technology (R&T) program, and as a strategic planning framework for other NASA and national participants

in advocating and conducting technology developments that support future U.S. civil space missions."<sup>2</sup>

In preparation of the ITP, OAST undertook an extraordinary effort. The ITP addresses the technology needs of all areas of NASA's space program and responds to inputs from the Office of Space Science and Applications (65 combined needs drawn from 98 inputs in various divisions); the Office of Exploration (approximately 25 needs); the Office of Space Flight (16 needs); and the Office of Space Communications (four needs). It also considers the technology needs of other government agencies (e.g., the National Oceanic and Atmospheric Administration has six needs), the commercial space industry (six need areas, e.g., launch vehicles), and recommendations of other advisory groups.

Of the more than 120 identified needs (over 100 being NASA), 20 were funded in FY 92 in the OAST focused program. Some items were responsive to identical inputs from multiple users, e.g., several users identified a need for advanced data systems.

The methodology employed in the development of the ITP was as follows:

- Step 1: Development of a forecast of future civil space flight programs and their technology needs and priorities.
- Step 2: Definition of an overarching strategy for technology maturation and transfer.
- Step 3: Development of a program structure and investment decision rules intended to support the maturation strategy.
- Step 4: Definition of the actual ITP Strategic Plan.
- Step 5: Development of specific annual programs and budgets.<sup>3</sup>

In the ITP, OAST identified three technology categories:

1. Technologies that are broadly applicable to several missions;
2. Technologies that are enabling for a specific mission concept or program objective (e.g., R&T pertaining to science instruments or Space Exploration Initiative (SEI) goals); and
3. Technologies that are of high value to user or mission offices planning similar systems (e.g., transportation technologies for OSSA deep-space missions and for the Space Exploration Initiative).

The ITP states that while OAST has not attempted to prioritize among various user plans, it has adopted "commonality and criticality" as the two general criteria for the evaluation of technology needs. The ITP notes that "the more common a technology need is, the more broadly an investment in that technology can be considered,"<sup>4</sup> but that other needs, though having only a single known use, may merit support because they are extremely important to, or enable, a mission or major mission objective.

OAST states that "in order to be fully successful, the ITP must constitute an overarching framework for civil space technology—and one for which there is a strong consensus within the aerospace and technology community that the ITP is in fact essentially correct."<sup>5</sup>

### Space Systems and Technology Advisory Committee Review

During the summer of 1991, NASA asked the Space Systems and Technology Advisory Committee (SSTAC) to review the ITP to fulfill Recommendation 8 of the Report of the Advisory Committee on the Future of the U.S. Space Program ("Augustine Committee") to "...utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds." The SSTAC's report was *Advanced Technology for America's Future in Space: A Review of NASA's Integrated Technology Plan for the Civil Space Program*. The SSTAC held a five-day meeting in the summer of 1991, which featured 65 review team members and 11 specific technology panels, each of which examined a major technical discipline area in the space R&T program. The review team included members of several advisory committees, including the Aeronautics and Space Engineering Board and the Space Studies Board, and other individuals with knowledge in space technology and related areas. The study was chaired by Dr. Joseph F. Shea of the Massachusetts Institute of Technology.

The SSTAC group concluded that "an effective process has been established to identify the advanced technology needs of the user communities and establish a rough order of priority within individual technical disciplines and program thrusts." It reviewed the ITP on the basis of two hypothetical funding levels. The first level was the "responsive plan," which attempted to address virtually all identified technology needs and presumed a growth from current space R&T funding levels to \$1.7 billion by 1997. The second level was the "three-fold augmentation plan" (based on a recommendation in the Augustine Committee's report) which "may realistically be all that NASA can be expected to invest...\$1.1 billion by 1997."<sup>6</sup>

The SSTAC group concluded that "the bulk of investment should be in technologies available five-to-fifteen years in the future, with more limited investment in R&T for deliverables closer than five or further than fifteen years" and that "the means of establishing priorities across disciplines and major thrusts needs to be further clarified." The summary recommendations of the SSTAC review are shown in Table 7.

Table 7

#### SUMMARY RECOMMENDATIONS: ADVANCED TECHNOLOGY FOR AMERICA'S FUTURE IN SPACE, P 4

Overall, the review team believes that Recommendation 8 of the Augustine Committee is well founded. NASA has instituted a sound planning process and the proposed Integrated Technology Plan for the Civil Space Program is a solid basis for responding to the Augustine Committee Recommendations on technology. Within each panel group, the review team found that at both the "three-fold increase" and the greater "responsive" resource levels, the proposed program was sound and that more, rather than less, resources were needed to meet the legitimate technology needs of the U.S. civil space program.

The Integrated Technology Plan deserves as much support as the Agency and Congress can provide. We also recommend that the Augustine target of a three-fold increase in funding level be the initial goal.

(continued)

(Table 7 continued)

**Summary Recommendations**

The review team believes, as was stated by the Augustine Committee's report, that "the development of advanced technology is ... crucial to the success of the exploration and exploitation of space." NASA's proposed Integrated Technology Plan responds to this challenge. Our most important and overriding recommendation for NASA, the Administration and the Congress is:

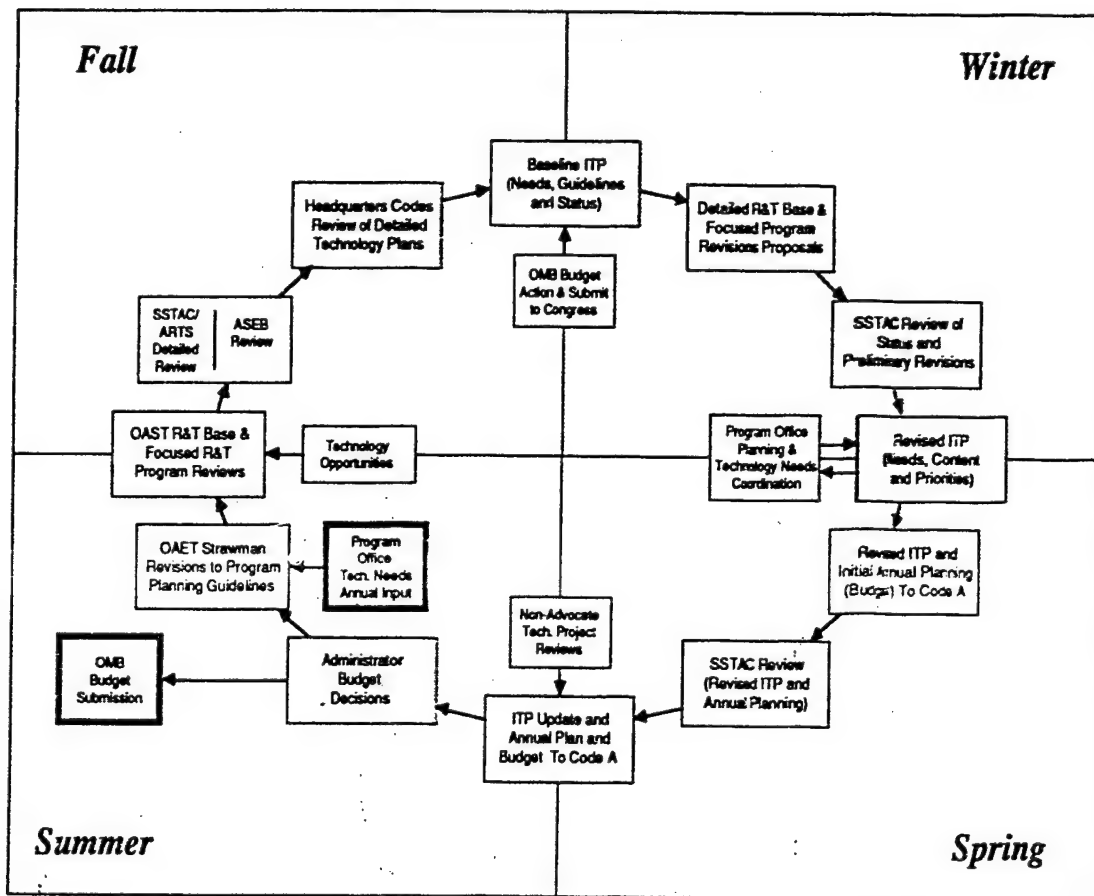
- Accept Recommendation 8 of the Augustine Committee and initiate planning for the needed funding growth to triple the current level of investment in advanced space research and technology.

In addition, the review team has the following subsidiary recommendations that arose during the review process:

- Continue to Improve the Integrated Technology Plan. NASA should continue to refine the space research and technology planning process, and increase the participation by other government agencies, industry and academia. Issues include: (1) improving technology transfer within the program, (2) establishing priorities across disciplines and thrusts, and (3) continuing and expanding the use of external, expert review of the program.
- Develop National Teams. Plan for and implement increased collaboration and teaming among NASA, industry and universities in space R&T, and coordination with other government agencies, as appropriate.
- Develop National Testbeds. Implement the concept of National Testbeds for space technology development.
- Revitalize Space R&T Facilities. Focus planning on a new generation of space technology research facilities.
- Increase the Use of Technology Flight Demonstrations. Implement policies and practices which reduce the cost and accelerate the pace of space R&T flight experimentation.
- Improve Technology Transfer. Focus management attention on developing clear, widely accepted criteria for adopting new technologies for future civil space flight programs.

**OAST'S SPACE TECHNOLOGY PROGRAM AND TECHNOLOGY NEEDS  
EVALUATION PROCESSES**

OAST has an elaborate set of processes to develop its program. These have some similarities to those of OSSA presented in Chapter 2. In keeping with the traditional role OAST has played in NASA, OAST's space emphasis is on continuous technology development in support of other parts of NASA. OAST's Space Technology Annual Research and Technology Planning and Budgeting Cycle is shown in Figure 5.



Source: NASA

**Figure 5** Annual space research and technology planning and budgeting cycle.<sup>7</sup>

The principles the OAST Space Technology Directorate has defined to meet its mission statement are listed in Table 8. For the most part, the OAST principles are compatible with and supportive of, the OSSA principles in Table 2. OAST's first principle, to "stress excellence," is congruent with OSSA's first principle, except that OAST includes ensuring the availability of support and facilities. However, simultaneously striving for excellence and working to maintain a capability are not necessarily compatible. The tension between these objectives is discussed further below. OAST's second principle is also parallel in spirit to OSSA's second principal, with OSSA stressing its service to the scientific community, and OAST stressing technology

transfer and responsiveness to customer needs. OAST reaffirms a necessary commitment to the ongoing R&T program as its third guiding principle while OSSA declares its intent to use scientific peer review in all aspects of its program. Other similar statements between OSSA and OAST relate to program balance and support of education. Unique OAST principles relate to its desire to use other organizations' capabilities when appropriate, and to contribute to the nation's competitiveness. Table 9 lists the stages of technology development that OAST employs in conducting its program.

Table 8

## OAST SPACE RESEARCH AND TECHNOLOGY PROGRAM PRINCIPLES

- Stress technical excellence and quality in all activities and ensure the availability of appropriate support and facilities.
- Be responsive to customers and assure technology transfer and utilization.
- Sustain commitment to ongoing R&T programs.
- Maintain the underlying technological strengths which are the wellspring of NASA's technical capability.
- Assure the introduction of new technology activities on a regular basis.
- Maintain balance among NASA customers, critical disciplines, and near- and far-term goals.
- Support science and engineering education in space R&T.
- Make effective use of technologies and capabilities of other government agencies, industry, academia and international partners.
- Enhance the nation's international competitiveness.

Table 9

## STAGES IN TECHNOLOGICAL MATURATION

Level	Definition
1	Basic Principles Observed and Reported
2	Technology Concept and/or Application Formulated
3	Analytical & Experimental Critical Function and/or Characteristic Proof of Concept
4	Component and/or Breadboard Validation in Laboratory Environment
5	Component and/or Breadboard Validation in Relevant Environment
6	System/Subsystem Model or Prototype Demonstration in a Relevant Environment (Ground or Space)
7	System Prototype Demonstration in a Space Environment
8	Actual System Completed and 'Flight Qualified' Through Test and Demonstration (Ground or Space)
9	Actual System 'Flight Proven' Through Successful Mission Operations

OAST defines Levels 1 and 2 in Table 9 as basic technology research, Levels 2 and 3 as research to prove feasibility, Levels 3 through 5 as technology development, Levels Five and Six as technology demonstration, Levels 6 through 8 as system/subsystem development, and

Levels 8 and 9, as system test, launch and operations. According to the ITP, transfer of projects from OAST to flight program offices (such as OSSA's science divisions) should occur between levels 3 and 6. In general, OAST seeks to advance technology through Level 5 in its space R&T activities.

In the ITP, OAST draws a distinction between its base program and its focused program as follows: "The space research and technology (R&T) Base is that portion of the R&T program within which NASA proposes to conduct discipline-oriented, 'technology push' activities." The ITP describes the focused part of the program as "that portion of the R&T program within which NASA proposes to conduct functionally oriented 'mission pull' activities."

OAST uses somewhat different decision rules for its base and focused programs. The decision rules for the base program are in Table 10, and the rules for the focused programs are in Table 11.

Table 10

OAST SPACE RESEARCH AND TECHNOLOGY BASE DECISION RULES

GENERAL RULES

- Use external reviews to aid in assuring program technical quality
- Provide stability by completing on-going discrete efforts

DISCIPLINE RESEARCH

- Assure adequate support to maintain high-quality in-house research capabilities in areas critical to future missions
  - Provide capabilities for ad hoc support R&T for flight programs
- Provide growth in R&T base areas needed for future focused programs
  - Coordinate with annual focused program planning
- Create annual opportunities for the insertion of new R&T concepts
  - Goal: Provide approximately 15-20 percent "roll-over" per year
- Support technology push flight experiments where space validation is required

IN-STEP FLIGHT PROGRAMS

- Maintain competitively selected studies/implementation of in-house and industry/university scale flight experiments, oriented on NASA's technology needs

UNIVERSITY PROGRAMS

- Evaluate to focus participation in NASA space R&T by U.S. universities and colleges—using competitive selection



Table 11

## OAST FOCUSED PROGRAM DECISION RULES

GENERAL

- Annually assess and fund projects in order of priority against mission-derived investment criteria
  - External review will be used to aid in assuring quality
  - Review with user offices will be used to aid in assuring relevance and timeliness
- Provide stability by completing on-going discrete efforts
- Start a mix of technology projects with short, mid- and long-term objectives each year
- Assure balanced investments to support the full range of space R&T users
- Fund new technology projects that have passed internal reviews as required (e.g., non-advocate review for major experiments)

MAJOR FLIGHT EXPERIMENTS

- Support competitively-selected implementation of in-house and industry major technology flight experiments in accordance with mission-derived prioritization criteria
- Fund major flight experiments where adequate ground-based R&T is underway or has been completed

OAST also has developed a set of criteria to rank the focused program elements with respect to projected missions. They are characterized as "investment prioritization criteria," and center upon mission need, programmatic and timing issues, and any special issues. Table 12 lists the ranking criteria.

The ITP describes the process and OAST focused program decision rules and criteria for determining which projects to fund as follows:

"The focused program decision rules were applied to the detailed program thrust, area and element technical strategic plans by teams of NASA personnel comprised of mission and flight programs personnel, mission operations personnel and NASA technologists. Using the focused program decision rules and evaluation criteria, and the strategic forecast of user mission plans and technology needs (and priorities), a prioritization of the focused program has been developed. The elements within each thrust have been identified as *highest priority*. Based on this prioritization, annual resource allocation decisions will be made."<sup>10</sup>

Table 12

## OAST FOCUSED PROGRAM MISSION-DRIVEN PRIORITIZATION CRITERIA

MISSION NEEDEngineering Leverage

Performance (Including Reliability) Leverage of the Technology to a System  
Importance of that Technology/System  
Performance to a Mission and Its Objectives

Cost Leverage

Projected Cost Reduction for a Given System/Option  
Projected Cost Reduction for Mission of that Savings

Breadth of Application

Commonality Across Missions/Systems Options  
Commonality Across Systems in Alternative Mission Designs

PROGRAMMATICS VERSUS TIMINGTimeliness of Planned Deliverables

Timing of the Mission Need for Technology Readiness  
Projected Duration of R&T Needed to Bring Technology to Readiness

Criticality of Timely R&T Results to Mission Decisions

Timing of Mission Planning Need for Technology Results  
Importance of Technology to Mission Objectives/Selection

Uncertainty in Planned R&T Program Success/ScheduleSPECIAL ISSUES

Readiness to Begin a Focused Technology Project  
Commitment to an Ongoing R&T Program  
Interrelationships to Other Government Program(s)  
Projected "National Service" Factors

## FINDINGS AND RECOMMENDATIONS

The ITP represents a key step toward rational management of NASA's space technology programs. The ITP contains a wide range of technologies that can contribute to future missions. Increased communication between technology developers and users was needed and has begun. The subsequent SSTAC review contributed further to the identification of NASA's technology needs by incorporating non-NASA opinions on those needs.

Since the ITP was conceived as a strategy to be annually revised to reflect mission planning and progress in ongoing technology development efforts,<sup>11</sup> the committee offers the following findings and recommendations to be considered as NASA continues its technology planning processes.

### 1. The Integrated Technology Plan is not yet an "agency-wide" technology plan.

There is little discernible coordination between OAST efforts in response to OSSA technology needs and the independent efforts underway by OSSA divisions to meet their own short- and long-term technology needs. In addition, there is little apparent coordination between OSSA divisions concerning their common technology needs. The ITP bears no imprint of the NASA Administrator, nor of agency-wide oversight and support.

The autonomy of NASA's offices can prevent OAST's resources from being diverted solely to support the near-term needs of flight missions, but can also prevent the development of a NASA strategy for the coherent application of the total agency resources. However, the Committee does not believe that the budget currently allocated to the OAST Space Technology Directorate should be transferred to OSSA and the other user groups inside NASA. In FY 1992, OAST's space technology budget was less than three percent of the NASA budget (\$306 million of \$14.3 billion) and OSSA has at times experienced (e.g., from 1990 to 1991) budget growth from one year to the next that was greater than the entire annual OAST space technology budget (see Figure 1). Furthermore, during the development of flight missions OAST scientists and engineers have been called upon to help solve particularly difficult technical problems. The expertise, capability, and promise that would be lost by dissolving OAST's space technology effort would be difficult to compensate for by comparatively small gains elsewhere.

Collaboration between the advanced technology efforts of OAST and OSSA should be enhanced. The technology needs submitted to OAST by OSSA did not specify which technologies OSSA divisions were already trying to develop in their own projects. This caused some confusion, and, in the future, OSSA should make special efforts to identify its divisions' most important needs and those needs that they are unable to address themselves, for potential joint projects or special consideration by OAST.

### 2. The diversity of the user communities that OAST serves makes the formulation of a common set of decision principles and rules for the prioritization and selection of new projects extremely difficult or impossible.

The needs and objectives of the civil space community are too diverse to be met by a single set of decision rules and criteria. The focused program decision rules in Table 11 or the base program rules in Table 10 provide little practical guidance on choosing between activities such as the development of a next-generation main engine for a launch vehicle, an advanced focal-plane array for a future mission to Jupiter, or the next advance in applications satellite design that may improve U.S. commercial interests. The rules provide no basis for a decision to allot 5, 10, or even 100 percent to space science and applications versus other major areas. Because NASA has not had direction from an agency-wide strategic plan, OAST has been forced to try to determine the agency's aims solely by polling the users of technology. Figure 6 summarizes the flow of user inputs and summarizes the results of the 1991/1992 process.

The OAST process described in the ITP is *encompassing*, but not necessarily *discriminating*. It would be feasible under the process to authorize nearly any space technology development activity that addressed any conceivable objective within the OAST mission statement. In choosing among the competitive voices of NASA offices and external needs, the allocation of resources to different major areas (e.g., space science and applications and space flight) ultimately reduces solely to an exercise in management judgment, rather than an organized process. However, once management has made the allocation to each major area, a distinct, logical process should guide the selection of tasks. Although no set of processes can eliminate the need for good judgment, the current situation relies very heavily on the assessments of key individuals.

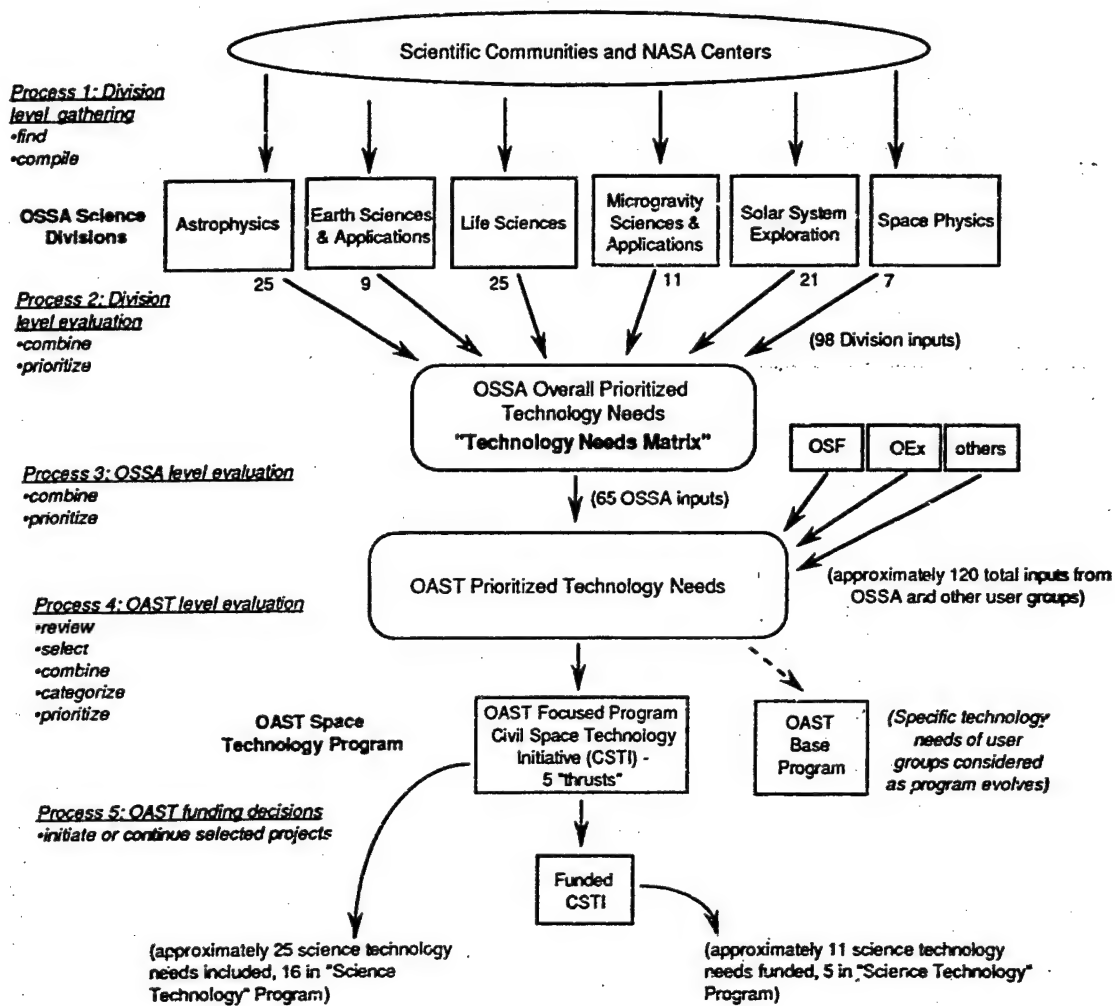
The current process is further clouded by the mixture of internal NASA needs and external national needs. In both cases, the question becomes one of whether OAST should make early investments to reduce the cost of other NASA or another organization's development programs. For some classes of technology, the lack of an OAST investment does not necessarily imply that the technology will not be developed, only that it may be developed through another program and on a different time scale. In instances where the technology is more speculative and high-risk, the lack of an OAST investment may indeed preclude a decision to employ advanced technology in a flight program.

Since OAST must determine which user's needs should receive priority, it should endeavor to acquire good information on which to base its decisions, and seek inputs from outside NASA. Although the space technology planning cycle in Figure 5 defines the time frame in which inputs must be received and decisions made, the process by which technology development opportunities are sought from the external community is not clear. It is also unclear how differences in judgment between external personnel and organizations are reconciled with NASA's views and its need to maintain a technological capability for future mission support.

**3. OAST has stated that "clear and effective prioritization of the various potential program elements is essential."<sup>12</sup> The Committee does not believe this has yet been achieved.**

The Committee believes the decision rules and criteria shown in Tables 9 and 10 and the process described in the ITP for their implementation are not sufficiently precise to enable objective ranking of technology needs. Since they do not pertain to the selection of individual projects, the decision rules could be more accurately described as guidelines for the management

**OSSA and OAST (ITP) Process for Identifying and Selecting  
Technology Needs for Space Science and Applications  
(with FY1992 data)**



**Figure 6** The FY 1992 flow of space science technology needs through OSSA and OAST.

of the focused space technology program. The prioritization criteria are imprecise and presented without accompanying metrics for their implementation.

It is very difficult for those outside the actual selection process to understand OAST's ranking of technology needs. The simultaneous consideration of several dozen technology needs without any described numerical or other systematic grading system (with recorded remarks and "grades" that can be referenced at a later date) is not realistic. The systematic consideration of many more projects than can be funded is not unknown to NASA: it need not grow into an unwieldy or overly complex bureaucratic undertaking.<sup>13</sup> For example, NASA releases Requests for Proposals (RFPs) to industry for spacecraft and other programs, and Announcements of Opportunity (AOs) and NASA Research Announcements (NRAs) to scientific communities for flight experiments, and evaluates responses regularly. It should be able to perform similarly in the selection of technology to be addressed by its focused space technology program.

OAST's need to evaluate submitted technology needs is akin to OSSA's need to evaluate proposed experiments. OAST's response should be as clearly stated, organized, and defensible.

#### **4. The mission model used for ITP planning is too optimistic.**

The mission model employed in this initial ITP is not consistent with NASA's budget. A more realistic mission model is needed. The mission model employed by OSSA and OAST falls between what might be done if there was a national mandate for the civil space program, like that in the 1960s for the Apollo program, and what is probably feasible within pragmatically projected budget ceilings. The missions described in the plan will likely occur at later dates than planned, and some will vanish altogether. The likelihood of early mission approval and execution is overestimated.

The optimism of the mission model sometimes promotes earlier investments in technology than may be appropriate. Because of the overall pace of world technology development, a development program may be undertaken prematurely and overtaken by other advances as the mission for which it is intended moves ever farther into the future. NASA does not wish to preclude future options by a lack of aggressive planning, but faces the danger of paying too much attention to missions that are several technological generations in the future.

In some disciplines, the amount of resources NASA can devote to a problem is vastly smaller than that which will be invested by others, e.g., in computation, telecommunications, bioinstrumentation, and other technologies driven by an extremely competitive marketplace. In these areas, NASA can at best only hope to keep pace with work done elsewhere or to address very narrowly-defined NASA needs by leveraging the larger investments of others.

#### **5. The ITP does not indicate how NASA can be responsive to the agency's technology needs in a flat funding environment.**

The initial ITP is based on two hypothetical funding levels: the "responsive plan"—\$1.7 billion by 1997—and the "three-fold augmentation plan"—\$1.1 billion by 1997 in 1991 dollars.<sup>14</sup> Even the smaller, three-fold augmentation plan would represent nearly a four-fold

increase over FY 91's \$295 million budget. A three-fold increase in six years would require approximately 20 percent annual real growth. To reach \$1.1 billion would require about 25 percent real annual growth and \$1.7 billion, a nearly six-fold increase, would require nearly 35 percent real annual growth. Since 1980, OAST has averaged slightly less than an annualized growth rate of nine percent (before adjusting for inflation), which is a little under five percent real annual growth, and about equal to NASA's overall growth rate. Thus, both funding assumptions are probably unrealistic, especially given current national economic and budgetary pressures.

The ITP must contain a plan for how OAST will determine not only which projects should be initiated or continued, but which should be canceled. Little emphasis has been placed on the critical evaluation of ongoing technology programs, or on the decision to cease work on projects that, for any of a variety of reasons, no longer merit support. In a flat or low-growth funding environment, such a plan is extremely important to maintain the viability of a program accustomed to growth.

It is critical that new innovations be welcomed even within a program that is unable to grow. To implement this recommendation, it is clear that some ongoing projects must be terminated or substantially reduced. To augment the current annual SSTAC review, NASA should regularly (perhaps every three years) subject its ongoing base R&T projects to competitive impartial reviews that are smaller and more directed to systematically "scrub" each segment of the program. As it modifies its programs, OAST should not limit research in its R&T base disciplines to NASA centers. Responding to projected mission needs is important, but a portion of NASA's technology program must respond to new, even high-risk, ideas that may yield large advances. The avoidance of risk should not be elevated to such a position that innovative but unconventional concepts are summarily dismissed.

**6. There are limited measures in place for continuing user involvement beyond the submission stage.**

The Committee finds that few formal processes for continued involvement of the user community are in place. As with flight programs (but to a lesser extent), the user community should retain a sense of investment in a project and not be involved only at the outset. The ongoing formal involvement of users can contribute to NASA's objectives by aiding technology transfer. Each technology project undertaken by OAST's focused program to meet OSSA's needs should have a clearly stated plan for shifting the project from OAST to an OSSA division, once the technology is sufficiently mature for the division to complete development for a particular application.

Some important factors to improve feedback must be addressed. It is unclear how a project in progress is examined by the potential final user, or even by the OSSA division that submitted the technology need that initiated the project. As a project proceeds, changes are inevitable. Frequently, weights increase, power requirements grow, capabilities diminish, costs exceed projections, schedules slip, and tradeoffs are necessary. Such occurrences in any high-technology, high-risk R&D project must be anticipated. If users are to retain a sense of



ownership of chosen tasks, they must be involved intimately in tracking the progress of the project, and have the opportunity to contribute to the resolution of problems.

**7. Although technology push in support of space science is a major component of OAST's R&T base program, this is not well known outside of OAST.**

OAST assigns to its R&T base program the primary responsibility for activities designed to create new space capabilities in advance of the expressed needs of users, i.e., technology push. The Committee believes that OAST should take specific measures to search more widely for ideas for technology push efforts and to make its support of space science in the base program more visible to those it aims to serve. The concerns noted above regarding seeking external inputs during program development are particularly important here.

#### NOTES

1. ITP, Chapter 2, section 7
2. ITP, p ii
3. Drawn from ITP pp 3-1,2
4. ITP, p 2-20
5. ITP, p 1-7 (*italics theirs*)
6. SSTAC, *Advanced Technology for America's Future in Space*, p 3
7. ITP, p 4-2
8. "Technology push" can be loosely defined as the situation wherein new advances enable new capabilities and, therefore, new mission designs or types of research.
9. "Mission pull" can be loosely defined as the situation where new technology development activities are initiated for the purpose of supporting a specific approved or proposed mission.
10. ITP, p 3-39
11. ITP, p ii
12. ITP, p 3-38
13. see also Naugle, *First Among Equals, the Selection of NASA Space Science Experiments*
14. SSTAC, *Advanced Technology for America's Future in Space*, p 3



## GENERAL FINDINGS AND RECOMMENDATIONS

### GENERAL FINDINGS

1. **The development of the Integrated Technology Plan has been an extraordinary undertaking and is a good first step towards improving OAST's approach to the development of technology for OSSA.**

The technology needs of the entire U.S. civil space program never before have been assembled and reviewed as they were in the ITP. However, the ITP does not lay out a plan for optimally addressing those needs with OAST's current budget. Furthermore, the ITP represents OAST's response to requested inputs, but does not reflect an agency-wide plan approved and backed by the NASA Administrator for the strategic application of NASA's sizable resources throughout the agency dedicated to aspects of technology development.

With respect to technology for space science and applications, the weaknesses in the ITP lie in what is not there rather than what is. OSSA has not consistently requested technological assistance with some of its most basic technology problems (e.g., technologies supporting earth observations and basic laboratory research onboard Space Station Freedom).

2. **Although the ITP is a step in the right direction, NASA has not yet developed processes for gathering, evaluating, and selecting possible technology development projects comparable to the systematic means it has used for scientific experiments for the last 30 years.**

OSSA methods for gathering scientific technology needs vary from division to division, and neither OSSA nor OAST presented a coherent methodology for evaluating and ranking combined technology needs. Both groups need systematic methods to numerically score space science technology needs on agreed-upon criteria (such as "engineering leverage," "cost leverage," and "breadth of application" in OAST's stated prioritization

criteria) and to make them comparable to one another through a composite score. This type of technique is used by OSSA in the selection of science experiments and has worked well.

The coordination of technology development work at OAST with OSSA division programs has suffered because once the submission of technology needs to OSSA (and eventually to OAST) has taken place there are limited measures in place for continuing scientific community involvement in subsequent decisions and projects.

3. **The organizational depth of the interaction between OSSA and OAST occurs primarily at the level of OSSA divisions and the OAST Space Technology Directorate. The degree of interaction varies widely from one OSSA division to another.**

For example, there has been no discernable interaction in the life sciences, there appears to be an onset of interaction in the microgravity sciences, and there has been an ongoing interface in astrophysics.

While the Committee was often reminded that OSSA and OAST managers were determined to improve communications to ensure an effective development process, there were few examples of the actual science users and technology developers teaming to insure a favorable result. The process of technology development could be enhanced, in many cases, by increased interaction between developers, users, and researchers.

4. **There is a wide disparity in the efforts of the OSSA divisions to determine their technology needs and act to address those needs.**

For example, the Astrophysics Division has committed significant resources to establishing its technology needs, while the Life Sciences, Space Physics, and Earth Sciences and Applications Divisions do not appear to have done so.

5. **OSSA's technology needs will be affected by NASA's potential paradigm shift toward "faster, cheaper, better" missions, including a shift of emphasis from big missions to more frequent access to space via smaller, more flexible, and more repeatable, missions.**

Because previous ITP projections were based on existing mission models, new projections will be necessary to promote more frequent and affordable missions. The Committee found little evidence of such requirements being identified by either office, although subsequent information indicates awareness within the science and technology communities of these new needs.

NASA's new initiative for smaller, less expensive, and more frequent missions is not simply a response to budget pressures; it is a scientific and technical imperative. Efficient

conduct of science and applications missions cannot be based solely upon intermittent, very large missions that require 10 to 20 years to complete. Mission time constants must be commensurate with the time constants of scientific understanding, competitive technological advances, and inherent changes in the systems under study (e.g., the Earth, its atmosphere, and oceans). This theme should be an important element of any agency-wide technology program.

6. **In spite of its pervasiveness and importance to NASA, there is no organized central control, information center, or focal point for NASA's technology development efforts.**

OAST, OSSA, and other NASA mission offices have completely independent technology development programs. While the Committee does not believe that these disparate activities should be consolidated, it does believe that technologists should be cognizant of related efforts sponsored by other NASA offices. Furthermore, since NASA has not had the direction that would come from an agency-wide strategic plan, OAST has been forced to try to determine the agency's aims solely by (1) polling the users of technology, and (2) incorporating a full-time OAST staff member in OSSA activities.

7. **With the establishment of judicious priorities, the present level of support allocated to OAST and OSSA by NASA should be sufficient to formulate, and to initiate the implementation of, a relatively small but responsive technology development program based on the key unmet needs of NASA's diverse science programs.**

However, the fraction of agency resources (at most \$177 million of \$14.3 billion — 1.2 percent) devoted to reducing technological risk in its major space science and applications programs is small. It does not appear adequate to reduce appreciably future risk or to seize many of the opportunities available to push the frontiers of technology.

8. **NASA and external users of technology are not well acquainted with the capabilities of, and constraints on, OAST.**

The OAST Space Technology budget is large in absolute terms, but small relative to its mandate to meet the technology needs of the U.S. civil space program and maintain crucial technical capabilities. Even if OAST devoted half of its current resources to specific space science needs, many worthwhile areas of research would not be addressed. On the other hand, OAST should make special efforts to work more closely with OSSA divisions to maximize the efficiency of NASA-internal work and increase use of the capabilities of universities to address NASA's long-term technology needs.

## GENERAL RECOMMENDATIONS

1. The NASA Administrator or OAST Associate Administrator should act to establish a coordinating position with the clear responsibility to ensure cooperation between technology development efforts within different parts of NASA—from early research through the various stages of technology development and readiness. An appropriate early task would be to extract information from the ITP to use in the formulation of an agency-wide working plan for technology for space science that is based on all of NASA's resources dedicated to this area. Such a plan would make visible NASA's many autonomous projects and foster an improved ability to evaluate and coordinate projects.
2. As NASA acts to improve its programs through the use of new or improved technologies, an emphasis should be placed on technologies with the potential to reduce end-to-end mission costs. Savings in real cost will enable more frequent access to space. Designing missions to be "faster, better, and cheaper" has the potential to improve NASA's performance in developing new technology for space science and should be put to the test in cases where significant scientific objectives can be met by spacecraft built on these principles.
3. OAST should bring increased rigor (including external review) to determining not only which projects should be initiated or continued, but which should be canceled. In a flat or low-growth funding environment this process will be extremely important to maintain the viability of a space science technology program.
4. Each OSSA division should endeavor to work closely with OAST in order to be involved in, or cognizant of, OAST's projects relevant to their technology needs. Stronger direction must come from top and middle managers regarding liaison between OSSA divisions and OAST focussed program efforts. Liaison groups, including staff from NASA centers, should be encouraged to identify and focus on high priority, feasible joint actions. Furthermore, additional OAST technical personnel could be assigned to OSSA programs on a part-time basis to provide for an ongoing exchange of technical information between the two offices. A possible pilot program for developing closer liaison is OSSA's highly technology-dependent Earth Observing System.
5. Since industry is heavily involved in the development of spacecraft and systems, and university scientists are heavily involved in the development of space instruments and sensors, OAST should increase the inclusion of representatives who are external to NASA in the early evaluation of users' technology needs and goals.
6. The OAST base program projects in support of space science should be subjected to more visible external review on a regular basis. OSSA representatives should be included with university and industry representatives in the review teams for relevant projects. The inclusion of OSSA staff and members of the outside scientific community

could contribute to a sense of investment in the OAST program in those it aims to serve, and facilitate the ultimate transfer of new technology to users.

7. **NASA should act to broaden the foundation of its research base by increasing the direct involvement of university research laboratories in the development of technology for space science. A specific emphasis should be on encouraging significant "enabling" developments rather than using universities to do work normally done by contractors.**
8. **OSSA should consider earmarking a modest level of funding for use at OAST on mutually agreed-upon projects. However, the Committee does not believe that the budget currently allocated to the OAST Space Technology Directorate should be transferred to OSSA and the other user groups inside NASA. The expertise, capability, and promise that would be lost by dissolving OAST's space technology effort would be difficult to compensate for by gains elsewhere.**
9. **Each OSSA division that has not yet done so should act to formalize technology planning responsibilities to identify, coordinate, and report relevant work within the division. Each should consider the development of a plan for technology that is integrated with its Strategic Plan, consistent with its programs, and approved by its director. OSSA divisions should consider empowering existing advisory working groups for particular scientific areas to identify technology needs, and contribute to their evaluation by examining subsequent sets of consolidated division-wide technology needs.**

## **ACRONYMS AND ABBREVIATIONS**

<b>ASEB</b>	<b>Aeronautics and Space Engineering Board</b>
<b>CSTI</b>	<b>Civil Space Technology Initiative</b>
<b>FY</b>	<b>Fiscal Year</b>
<b>IN-STEP</b>	<b>In-Space Technology Experiment Program</b>
<b>ITP</b>	<b>Integrated Technology Plan for the Civil Space Program</b>
<b>NASA</b>	<b>National Aeronautics and Space Administration</b>
<b>NRC</b>	<b>National Research Council</b>
<b>OAST</b>	<b>Office Of Aeronautics and Space Technology</b>
<b>OSSA</b>	<b>Office of Space Science and Applications</b>
<b>R&amp;T</b>	<b>Research and Technology</b>
<b>RTOP</b>	<b>Research and Technology Operating Plans</b>
<b>SEI</b>	<b>Space Exploration Initiative</b>
<b>SSB</b>	<b>Space Studies Board</b>
<b>SSTAC</b>	<b>NASA Space Systems and Technology Advisory Committee</b>

## **BIOGRAPHICAL SKETCHES OF COMMITTEE MEMBERS**

**JOHN H. McELROY** is Dean of Engineering and Professor of Electrical Engineering at the University of Texas at Arlington. He was formerly a vice president for technology at Hughes Communications, Inc., joining Hughes in 1985 as Director of Special Projects in the Space and Communications Group. Prior to this he was Assistant Administrator for Satellites of the National Oceanic and Atmospheric Administration, where he directed the nation's program in civil operational Earth observations from space. From 1966 to 1982, he served with NASA, where his last position was Deputy Director of the Goddard Space Flight Center. He received his Ph.D. in Electrical Engineering from Catholic University of America in 1978. He was named the Wernher von Braun Memorial Lecturer by the Smithsonian Institution for 1986. He is currently a member of the NRC's Space Studies Board, chairs its Committee on Earth Studies, and is a past member of the Aeronautics and Space Engineering Board.

**JOHN M. HEDGEPEETH** is President of Digisim Corporation and until 1983, was President of Astro Aerospace Corporation. From 1960 to 1967, he was a manager at Martin Marietta where he rose to the position of Deputy Director of Engineering. From 1948 to 1960, he conducted and led research for the National Advisory Committee on Aeronautics, and subsequently NASA. He received his Ph.D. in Applied Mathematics from Harvard in 1962. His research interests include structures and aeroelasticity, magnetohydrodynamics, large space systems, and deployable space structures. He is member of the Aeronautics and Space Engineering Board and co-chairman of the ASEB/SSB Joint Committee on Technology for Space Science and Applications.

**DAVID A. LANDGREBE** is Professor of Electrical Engineering at Purdue University from which he received his Ph.D. in 1962. He has held positions at the Bell Telephone Laboratories, Interstate Electronics Corporation and the Douglas Aircraft Company. He is the author of numerous scientific publications in the fields of data representation, analysis and remote sensing and is a member of the editorial board of the journal "Remote Sensing and Environment. Dr. Landgrebe was awarded the NASA Exceptional Scientific Achievement Medal in 1973 for his work in the field of machine analysis methods for remotely-sensed Earth resources data. He is member of the Space Studies Board and co-chairman of the ASEB/SSB Joint Committee on Technology for Space Science and Applications.



THEODORE M. ALBERT retired from the U.S. Geological Survey (USGS) in 1989 and is currently a consultant. While at the USGS, Mr. Albert's responsibilities included the development of databases, evaluation of data storage techniques, and the establishment of federal Earth science data standards. Prior to joining the USGS in 1978, he was Director of the Office of Environmental Information Systems for the Department of Energy and held positions with Westinghouse Electric and a technical consulting firm. Mr. Alberts received his M.S. degree from the Georgia Institute of Technology in 1965, and a B.A. in Mathematics from the University of South Florida.

JEFFREY R. ALBERTS is Professor of Psychology and Associate Dean of the Office of Research and the University Graduate School at Indiana University. He received his Ph.D. in Psychology from Princeton University in 1974. His research interests include developmental psychobiology, animal behavior, and the environmental requirements of research animals. He is the Indiana University Co-Director of the Indiana Space Grant Consortium which also involves Purdue and Notre Dame Universities. In 1983, he was a principal investigator in the Soviet-U.S. Cosmos-1514 Biosatellite mission.

JAMES G. ANDERSON is Philip S. Weld Professor of Atmospheric Chemistry at Harvard University. He received his Ph.D. in Physics/Astrogeophysics from the University of Colorado in 1970. Dr. Anderson was Mission Scientist for the NASA Airborne Arctic Stratospheric Experiment II; the results of his research have significantly contributed to understanding the effect of chlorofluorocarbons (CFCs) on the Earth's atmosphere and have been used in the development of the international protocols controlling the use of CFCs. Dr. Anderson is a member of the National Academy of Sciences.

WILLIAM V. BOYNTON is a professor in the Department of Planetary Sciences at the University of Arizona. He received his Ph.D. from Carnegie Mellon University in Physical Chemistry. His research interests include planetary surface composition, meteorites, comets, and trace element condensation from the solar nebula. He is a team leader and principal investigator for the Mars Observer mission, a co-investigator for the Cassini mission to the outer solar system, and has served on several advisory groups and committees for NASA and the NRC.

WILLIAM M. BURNETT is Senior Vice President for Research and Development Management for the Gas Research Institute (GRI) in Chicago, Illinois where he has developed a project appraisal methodology used to prioritize their research and development programs. Mr. Burnett began his career as a physicist for the Naval Ordnance Station in 1966 and served in various positions with responsibility for R&D efforts on rocket and gun propulsion systems. He received an M.S. in Aerospace Engineering from Norwich University in 1972, and a B.S. in Physics from the University of Maryland in 1965. Mr. Burnett has served as a past member of NRC Energy Engineering Board Review Panels.



SAM R. CORIELL is a physical chemist who has performed research in the Metallurgy Division of the National Institute of Standards and Technology for nearly 30 years. He received his Ph.D. in Chemistry from Ohio State University in 1961. His research interests include crystal growth, solidification, heat flow, diffusion, and fluid mechanics. Dr. Coriell has been active in the microgravity sciences research community, chairing the 1989 Gordon Research Conference on Gravitational Effects in Materials and Processes, and serving on NASA advisory boards in this area.

ANDREA K. DUPREE is a senior astrophysicist at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts. Dr. Dupree received her Ph.D. from Harvard University in 1968, and has been an investigator on many space-based and ground-based astronomical research projects. Her research interests include solar and stellar atmospheres, the interstellar medium, and high resolution spectroscopy. From 1980-1987, Dr. Dupree was Associate Director of the Harvard-Smithsonian Center for Astrophysics and Head of the Solar and Stellar Physics Division. Dr. Dupree has served two terms on the NRC's Space Studies Board, is a former vice president of the American Astronomical Society, and has served on numerous other boards and committees for groups including the NRC, NASA, and the Committee on Space Research (COSPAR).

ANTHONY W. ENGLAND is presently a professor of electrical engineering at the University of Michigan. He was a NASA scientist-astronaut from 1967 to 1972; performed research in Antarctica, and was Deputy Chief of the Office of Geochemistry and Geophysics during his 1972-1979 affiliation with the U.S. Geological Survey; and was a senior scientist and Space Shuttle astronaut with NASA from 1979 to 1988. Dr. England was a mission specialist on Spacelab 2 in 1985 which included research on solar, plasma, and atmospheric physics. He received his Ph.D. in Geophysics in 1970 from the Massachusetts Institute of Technology.

PAUL D. FELDMAN is a professor of physics and astronomy at the Johns Hopkins University, where he has taught since 1967. Dr. Feldman received his Ph.D. in atomic physics from Columbia University in 1964 and was a research associate at the Naval Research Laboratory from 1965-1967. His research interests include the atmospheres of Earth and the planets and ultraviolet astronomy. He was a principal investigator on the 1990 ASTRO-1 Space Shuttle mission, is a trustee of the University Space Research Association and a former member of the NRC's Committee on Planetary Exploration.

ROBERT E. FISCHELL is currently a principal staff physicist at The Johns Hopkins University, Applied Physics Laboratory (APL) and President of MedInTec, Inc. Mr. Fischell has been associated with the APL since 1959 and was formerly Chief Engineer and Chief of Technology Transfer for its space department. Mr. Fischell is also affiliated with both the Johns Hopkins and Yale University Schools of Medicine. He is a member of the National Academy of Engineering, has been an innovator in spacecraft and biomedical engineering for over 30 years and received numerous awards for his inventions and other engineering achievements. He received his M.S. degree in Physics from the University of Maryland in 1953, and a B.S. degree in Mechanical Engineering from Duke University in 1951.

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FRANK B. McDONALD is currently a senior research scientist at the Institute for Physical Science and Technology at the University of Maryland. He has spent nearly 30 years of his career with NASA—at Goddard Space Flight Center and NASA Headquarters, and was NASA's Chief Scientist from 1982 to 1987. During his service at Goddard he contributed to, and managed, the design and the development of many scientific instruments and satellites. His research interests include the study of galactic and solar cosmic rays, and astrophysics in general. Dr. McDonald received his Ph.D. from the University of Minnesota in 1955 and is a member of the National Academy of Sciences.

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FRANKLIN K. MOORE is Joseph C. Ford Professor of Mechanical Engineering at Cornell University. His research interests include thermal engineering, boundary layer theory, propulsion, power systems heat rejection, and thermal pollution. He received a Ph.D. in aeronautical engineering from Cornell in 1949, worked for the National Advisory Committee on Aeronautics (NACA) from 1949 to 1955 and has twice served as a visiting senior scientist at NASA Headquarters during the 1980s. Dr. Moore is a member of the National Academy of Engineering and past member of the Aeronautics and Space Engineering Board.

RICHARD K. MOORE is Black and Veatch Professor of Electrical Engineering and Director of the Radar Systems and Remote Sensing Laboratory at the University of Kansas. He received a Ph.D. from Cornell University in Electrical Engineering in 1951 and has held positions at RCA Victor, Washington University, and Cornell University. His research interests include submarine, tropospheric, and ionospheric wave propagation, radar systems, and the application of radar and radio wave propagation to Earth sciences. Dr. Moore is a member of the National Academy of Engineering and a former member of the Space Studies Board.

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GEORGE F. SMITH spent 35 years at the Hughes Research Laboratories, first as a research scientist, and then in a leadership role. When he retired in 1987, he was Senior Vice President of Hughes Aircraft Company, and had been Director of the Laboratories since 1969. Under his leadership, the Hughes Laboratory made significant contributions to electronics, lasers, electro-optics, artificial intelligence, and was able to successfully transfer new technologies into operational devices for military and space systems. He received a Ph.D. in Physics from the California Institute of Technology in 1952. From 1946-1948 Dr. Smith was one of a dozen founding members of Engineering Research Associates, which later became the Univac division of Sperry.

JOHN W. TOWNSEND retired in 1990 after 3 years as Director of NASA's Goddard Space Flight Center after a total of 34 years in Federal service. He received B.A., M.A., and Sc.D. (Hon) degrees from Williams College. He began his career at the Naval Research Laboratory in 1949 as a physicist instrumenting V-2, Viking and Aerobee sounding rockets for upper air research, and joined NASA at its inception in 1958. In 1970 he became the Associate Administrator of the National Oceanic and Atmospheric Administration. He left the government in 1977 and joined Fairchild Industries for ten years where he held positions including Executive Vice President and President of the Fairchild Space Company. Dr. Townsend is a member of the National Academy of Engineering.

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National Aeronautics and Space Administration. Workshop Proceedings: Technologies for Large Filled-Aperture Telescopes in Space, Mission Concepts and Technology Requirements. Volume 4, Astrotech 21 Workshops Series II.

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## APPENDIX A

### STUDY ORIGIN AND STATEMENT OF TASK

In early 1990, members of the Space Studies Board (SSB) and Aeronautics and Space Engineering Board (ASEB) recognized a need for the space science and space engineering communities to interact and exchange views. The SSB and ASEB were encouraged by NASA Associate Administrators Lennard Fisk of the Office of Space Science and Applications (OSSA) and Arnold Aldrich of the Office of Aeronautics and Space Technology (OAST), who wrote to the chairmen of the SSB and ASEB requesting that the boards "explore the formation of a joint committee on technology for space science and applications." The Associate Administrators noted that they "would be pleased to see closer working arrangements between the SSB and ASEB, particularly in the areas of identifying, evaluating, and recommending critical technology developments needed for the realization of our national goals for space science and applications."

The two boards formed a Joint Committee on Technology for Space Science and Applications that began to investigate ways in which the boards could combine their areas of expertise to provide a new service to NASA. They decided that a series of studies on topics of concern to both the space science and space engineering communities would be a valuable way of opening the dialogue between the two groups.

In December 1991, OSSA and OAST suggested that the Joint Committee consider reviewing NASA's plans for developing new technologies in support of future space science and applications programs as described in OAST's *Integrated Technology Plan*. In accordance with the statement of task in Appendix A, the ASEB/SSB Joint Committee assembled a broadly representative group, named the Committee on Space Science Technology Planning, that was comprised of 26 engineers and scientists (including the seven members of ASEB/SSB Joint Committee) to conduct the review. The statement of task at the initiation of the study follows.



## STATEMENT OF TASK

The NASA Office of Space Science and Applications (OSSA) and Office of Aeronautics and Space Technology (OAST) both develop technology for future space science and applications missions. OSSA's technology development efforts are undertaken by its six science divisions which manage specific technology-dependent programs and focus their development efforts primarily on requirements for relatively near-term missions. As part of its strategic planning, OSSA has developed a "Technology Needs Matrix" containing several dozen technological areas or devices that it considers crucial. OAST, on the other hand, has the responsibility to assist OSSA and the other NASA offices with technology requirements that could enable or enhance future missions and has recently completed an "Integrated Technology Plan" (ITP). The committee will examine the processes by which the OSSA Technology Needs Matrix and the OSSA-derived portion of ITP were developed in order to identify means of optimizing the future development of technology for space science and applications.

The centerpiece of this study will be a 4- to 5-day workshop. During the workshop the committee will specifically:

1. Review the NASA-supplied background information on each of the elements in the OSSA Technology Needs Matrix.
2. Review and critique the NASA decision rules and criteria used in developing the matrix and OAST's response.
3. Critique the technological objectives and the Technology Needs Matrix elements, identifying gaps when possible.
4. Evaluate the compilation process and the ranking as derived from the rules.
5. Suggest any necessary modifications to the rules.

Additional topics which may be included in the Joint Committee's report may include:

1. An evaluation of OSSA's and the U.S. space science and application community's stated long-term technology needs.
2. Identification of those development projects that OSSA itself anticipates undertaking, those appropriate for OAST, and those that might be undertaken jointly.
3. Suggestions regarding mechanisms to improve coordination and transfer of knowledge and technology between OSSA and OAST.

The Committee will prepare a report to the NASA Associate Administrators of OAST and OSSA. The report will be subject to National Research Council report review procedures before release.

## **APPENDIX B**

### **WORKSHOP PARTICIPANTS**

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## APPENDIX C

### ESTIMATING NASA FUNDING FOR TECHNOLOGY FOR SPACE SCIENCE

Three different analyses of the current OAST budgetary expenditure on technology for space science and applications follow along with corresponding budget charts.

The first, and most conservative, method was simply to consider the funding for the five technology needs addressed in the Space Science Technology thrust of the OAST focused program as representing OAST's efforts on behalf of OSSA. As shown in the first row of Table C1, in FY 1992 this sum was \$13.5M and amounted to 4 percent of OAST Space Technology Budget and 9 percent of the focused program budget. This accounting is inadequate because it does not consider projects funded in other focused program thrusts or the base program that are responsive to the OSSA's needs.

The second method was to review the stated OSSA technology needs that are addressed in any of the five thrusts of OAST's focused program. This simple analysis, using only the ITP and the Workshop presentations made by OAST, shows that 11 of the 20 areas in the OAST focused program are, at least on first review, related to stated OSSA technology needs. These areas are shown underlined in Table C-1. OAST projects based on these technology needs sum to \$41.2M—14 percent of the OAST Space Technology budget and 28 percent of the focused program budget. The efforts underway in the OAST base program were inaccessible and make this estimate a partial one. The technology need funding breakdown that the first two estimates are drawn from is shown in the Table entitled "FY 1992 OAST Focused Program."

For an all inclusive estimate, the Committee asked NASA to review OAST's focused and base programs and provide their best estimate of the FY 1992 OAST efforts on behalf of OSSA. NASA's analysis, presented in Table C-2, includes less obvious work underway in the focused program and work done in the base program that was not estimable by the Committee. NASA estimates that \$60.5M (40 percent) in the focussed program, and \$67.8M (44 percent) of the base program (\$128.3M and 42 percent of the overall of OAST Space Technology budget), supports work responsive to OSSA's needs. These data and OSSA's expenditures in support of technology development are summarized in Figure C-1. Table C-3 presents more specific data on the technology expenditures of the OSSA divisions.

Table C-1 FY 1992 OAST Focused Program Elements (Elements Responsive to OSSA's Technology Needs Underlined)

FY 1992 OAST FOCUSED PROGRAM					
Space Science Technology	<u>Submillimeter Sensing</u> (1.2M)	<u>Direct Detectors</u> (5.1M)	<u>Laser Sensing</u> (3.6M)	—	—
(Total for ITP Science Needs: \$13.5M of \$13.5M)	<u>Cooler and Cryogenics</u> (3.6M)	<u>Microprecision CSI</u> (0)	—	—	—
Planetary Surface Technology	<u>Radiation Protection</u> (1.5M)	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power	—
(Total for ITP Science Needs: \$3.5M of \$30.0M)	—	—	<u>Extravehicular Activity Systems</u> (2.0M)	—	Laser-Electric Power Beaming
Transportation Technology	ETO Propulsion	Nuclear Thermal Propulsion	—	—	—
(Total for ITP Science Needs: \$1.5M of \$37.8M)	—	Advanced Cryogenic Engines	—	<u>Nuclear Electric Propulsion</u> (1.5M)	—
Space Platforms Technology	Platform Structures & Dynamics	<u>Platform Power and Thermal Mgt.</u> (5.0M)	—	—	—
(Total for ITP Science Needs: \$5.0M of \$25.8M)	—	—	—	—	—
Operations Technology	<u>Space Data Systems</u> (4.9M)	—	<u>Artificial Intelligence</u> (12.8M)	—	—
(Total for ITP Science Needs: \$17.7M of \$42.7M)	—	—	TeleRobotics	—	—
<u>Total for ITP Science Needs:</u> \$41.2M of \$149.8M	HIGHEST PRIORITY			2nd HIGHEST PRIORITY	

Table C-2 Funding Data for OSSA Divisions; and OSSA Division, OAST Focused Program, and OAST Base Program Expenditures to Technology for Space Science and Applications

OSSA/OAST FY 1992 TECHNOLOGY BUDGETS					
OSSA Division	Budget Total	R&A Budget	OSSA Technology Development	OAST Focused Program	OAST Base Program
	(\$M)	(\$M)	(\$M)	(\$M)	(\$M)
Astrophysics	683.7	35.5	11.3	10.6	15.9
Earth Science and Applications	747.5	175.1	10.0 <sup>a</sup>	17.8	15.3
Life Sciences	148.9	50.7	5 <sup>a</sup>	6.5	8.9
Microgravity Science and Applications	120.8	16.6	8.0 <sup>a</sup>	0.0	4.4
Solar System Exploration	534.5	90.7	5.5	19.8 <sup>a</sup>	13.8
Space Physics	275.6	35.0	3.5	.1	8.2
Flight Systems	88.0	—	—	—	—
Other:					1.3 (systems analysis)
Research Operations	82.3	—	—		
Information	35.0	—	3.5		
Communications	12.5	—	—		
Innovative Research	—	—	2.0		

TOTAL \$2728.8M \$403.6M \$48.8M \$54.8M

[+ \$5.7M (HPCC)]

\$60.5M out of \$150M \$67.8M out of \$155M

\$128.3M out of \$305M

M = millions of dollars

HPCC = High Performance Computing & Communications

<sup>a</sup>No Advanced Technology Development budget line in Earth Sciences or Life Sciences

<sup>a</sup>Not part of Research & Analysis Budget

<sup>a</sup>Includes 11.3 for Nuclear Electric Propulsion (including SP100)

Source: NASA

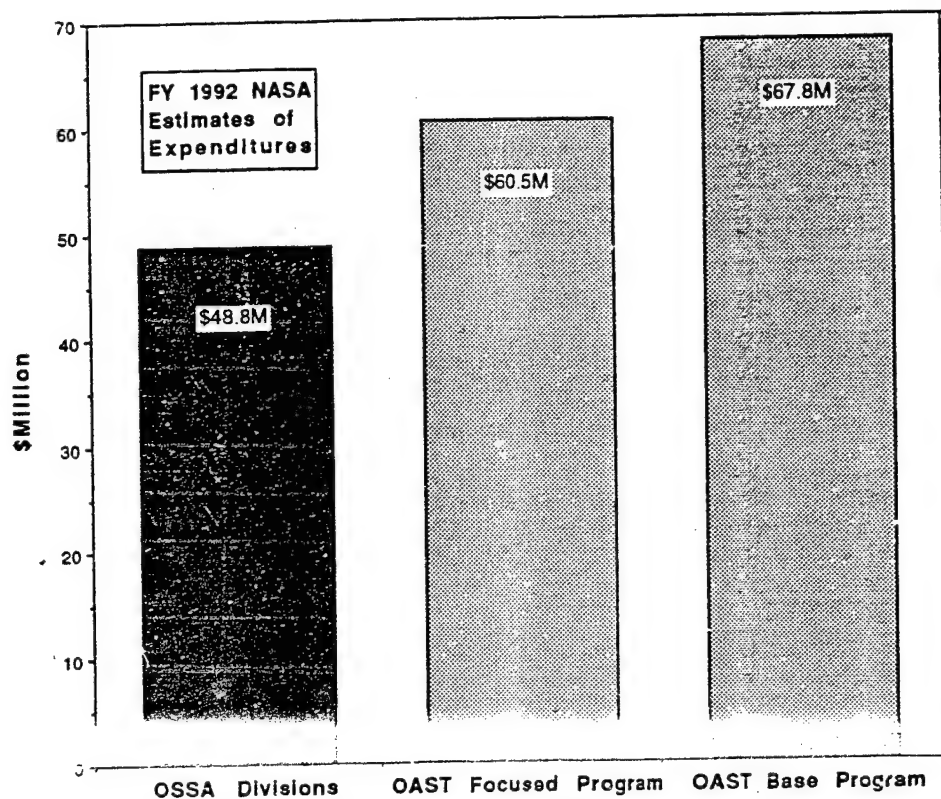


Figure C-1 Spending on technology development for space science applications.

Table C-3 FY 1992 OSSA Technology Development Expenditures, by Division

FY 1992 OSSA TECHNOLOGY DEVELOPMENT EXPENDITURES			
OSSA Division	Technology Spending (\$M)	Percent Peer Reviewed	Percent In-House
Astrophysics	$\geq 11.3$	100%	41%
Earth Science and Applications	$\leq 10$	100%	50%
Life Sciences	$\leq 5$	20%	80%
Microgravity Science and Applications	$\sim 8$	100%	45%
Solar System Exploration	$\leq 5.5$	100%	30%
Space Physics	$\leq 3.5$	52%	50%
Flight Systems — Information Systems	$\sim 3.5$	85%	35%
Innovative Research	2	100%	0%

Source: NASA



## APPENDIX D

### PAST RECOMMENDATIONS ON TECHNOLOGY FOR SPACE SCIENCE

#### ASEB: NASA'S SPACE RESEARCH AND TECHNOLOGY PROGRAM

Five institutional recommendations were made in the ASEB's 1983 report, *NASA's Space Research and Technology Program*. They are given in Table D-1. In addition, 13 recommendations were made regarding the specific technologies to be pursued. These are given in Table D-2.

Table D-1

Institutional Recommendations from the ASEB Report, NASA's Space Research and Technology Program

- NASA should establish the level of resources (funds, manpower, and facilities) to be allocated to advanced space research and technology development for the next decade and protect these resources from the short-term requirements of NASA's major operational programs.
- NASA should expand the charter of its space technology advisory committees, charging industry and university members with the responsibility of helping NASA to plan a technology program that is responsive to the needs of the broader space community and not just to NASA's in-house needs.
- NASA-DOD cooperation in space R&T should grow.
- NASA should develop centers of technological excellence.
- NASA should provide access to space for experimental purposes as a natural extension of national aerospace facilities.

Table D-2

**Technological Recommendations from the ASEB Report, NASA's Space Research and Technology Program**

- Reduce the cost of using space.
- Advance on-orbit propulsion technology.
- Enhance technology for large space structures.
- Develop a database on materials properties in the space environment.
- Reduce the time and costs involved in obtaining data from space in usable formats.
- Enhance sensor capabilities.
- Advance space communications technologies.
- Improve the lifetime, reduce the weight, and increase the energy storage capabilities of space power systems.
- Enhance the protection of systems from the space environment.
- Improve the analytical foundations and engineering techniques for advanced thermal control systems for spacecraft.
- Enhance the capabilities and autonomy of space navigation, guidance, and control systems.
- Advance the technologies for the support of humans in space.
- Improve the survivability, self-diagnostic, and self-correction capabilities of spacecraft.

**PIONEERING THE SPACE FRONTIER**

Three years later, and after the implementation of many of the recommendations of the 1983 ASEB report, the Paine Commission report, *Pioneering the Space Frontier*, delivered a sweeping vision of the nation's future in space. The report recommended a major augmentation of NASA's technology base effort. These recommendations are given in Table D-3.

Table D-3

**Recommendations of the Paine Commission Regarding the Technology Base**

The United States must substantially increase its investment in its space technology base. We recommend: A threefold growth in NASA's base technology budget to increase this item from two percent to six percent of NASA's total budget... We also recommend: Special emphasis on intelligent autonomous systems. We recommend demonstration projects in seven critical technologies:

- Flight research on aerospace plane propulsion and aerodynamics;
- Advanced rocket vehicles;
- Aerobraking for orbital transfer;
- Long-duration closed-ecosystems (including water, air, and food);
- Electric launch and propulsion systems;
- Nuclear-electric space power; and
- Space tethers and artificial gravity.

### ASEB: SPACE TECHNOLOGY TO MEET FUTURE NEEDS

After the Paine Commission report, NASA requested the ASEB to revisit its earlier recommendations and to examine them in light of the environment that existed after the National Commission on Space's efforts and in the aftermath of the loss of Challenger. This led to the second ASEB report, *Space Technology to Meet Future Needs*. The report recommended that no less than seven percent and as much as 10 percent of the NASA budget should be devoted to advanced technology R&D. The principal recommendations are given in Table D-4.

Table D-4

**Recommendations of the ASEB Report, Space Technology to Meet Future Needs**

- |   |  |
|---|--|
| <ul style="list-style-type: none"> <li>• Advanced propulsion               <ul style="list-style-type: none"> <li>- Advanced Earth-to-orbit engines</li> <li>- Reusable cryogenic orbital transfer vehicles</li> <li>- High-performance orbital transfer systems for sending humans to Mars</li> <li>- New spacecraft propulsion systems for solar system exploration</li> </ul> </li> <li>• Humans in space               <ul style="list-style-type: none"> <li>- Radiation protection</li> <li>- Closed-cycle life support systems</li> <li>- Improved EVA equipment</li> <li>- Autonomous system and robotic augmentations for humans</li> <li>• Human factors research</li> </ul> </li> <li>• Autonomous systems and robotics               <ul style="list-style-type: none"> <li>- Lightweight, limber manipulators</li> <li>- Advanced sensing and control techniques</li> <li>- Teleoperators</li> <li>- Artificial intelligence and advanced information processing systems</li> </ul> </li> <li>• Space power supplies               <ul style="list-style-type: none"> <li>- 100 Kw nuclear power source</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>• Materials and structures               <ul style="list-style-type: none"> <li>- Advanced metallic materials based on alloy synthesis</li> <li>- "Hot" structures to counter reentry heating</li> <li>- "Trainable" control systems for large flexible structures</li> </ul> </li> <li>• Information and control               <ul style="list-style-type: none"> <li>- Autonomous on-board computing systems</li> <li>- High-speed, low-error rate digital transmission over long distances</li> <li>- Voice/video communications</li> <li>- Spaceborne tracking and data relay</li> <li>- Equipment monitoring technology</li> <li>- Ground data handling, storage, distribution, and analysis</li> </ul> </li> <li>• Advanced sensor technology               <ul style="list-style-type: none"> <li>- Large aperture optical and quasi-optical systems</li> <li>- Detection devices and systems</li> <li>- Cryogenic systems</li> <li>- In-situ analysis and sample return</li> </ul> </li> <li>• Supporting technologies               <ul style="list-style-type: none"> <li>- Radiation insensitive computational systems</li> <li>- High-precision attitude sensors and axis transfer systems</li> </ul> </li> </ul> |
|---|--|

## LEADERSHIP AND AMERICA'S FUTURE IN SPACE

After the loss of Challenger, and the Rogers Commission report describing its causes, and with the Paine Commission report in hand, NASA management asked Dr. Sally Ride to provide NASA's response and a perspective for the future. This led to the report, *Leadership and America's Future in Space*, that has largely formed the manner in which NASA's missions for the future are categorized. The report defines four bold initiatives: Mission to Planet Earth (Table D-5), Exploration of the Solar System (Table D-6), Outpost on the Moon (Table D-7), and Humans to Mars (Table D-8).

Table D-5

**Ride Report Statement of the Technology Requirements for the Mission to Planet Earth**

This initiative requires advances in technology to enhance observations, to handle and deliver the enormous quantities of data, and to ensure a long operating life. Sophisticated sensors and information systems must be designed and developed, and advances must be made in automation and robotics (whether platform servicing is performed by astronauts or robotic systems).

To achieve its full scope, this initiative requires the operational support of Earth-to-orbit and space transportation systems to accommodate the launching of polar and geostationary platforms.

Table D-6

**Ride Report Statement of the Technology Requirements for the Exploration of the Solar System**

As it is defined, this initiative places a premium on advanced technology and enhanced launch capabilities to maximize the scientific return. It requires aerobraking technology for aerocapture and aeromaneuvering at Mars, and a high level of sophistication in automation, robotics, and sampling techniques. Advanced sampling methods are necessary to ensure that geologically and chemically varied and interesting samples are collected for analysis.

The Solar System Exploration initiative significantly benefits from improved launch capability in terms of the science returned from both the Mars and the Cassini missions.

The Space Shuttle is not required for any of the missions in the initiative. The Space Station would not be needed until 1999, when an isolation module may be used to receive the Martian samples.

Table D-7

**Ride Report Statement of the Technology Requirements for the Outpost on the Moon**

This initiative envisions frequent trips to the Moon after the year 2000--trips that would require a significant investment in technology and in transportation and orbital facilities in the early 1990s.

The critical technologies for this initiative are those which would make human presence on the Moon meaningful and productive. They include life-support system technologies to create a habitable outpost; automation and expert systems and surface power technologies to make the outpost functional and its inhabitants productive; and lunar mining and processing technologies to enable the prospecting for lunar resources.

The transportation system must be capable of regularly transporting the elements of the lunar outpost, the fuel for the voyage, and the lunar crew to low-Earth orbit. The Space Station is an essential part of this initiative. As the lunar outpost evolves, the Space Station would become its operational hub in low-Earth orbit. Supplies, equipment, and propellants would be marshalled at the Station for transit to the Moon. It is, therefore, required that the Space Station evolve to include spaceport facilities.

Table D-8

**Ride Report Statement of the Technology Requirements for Humans to Mars**

A significant long-term commitment to developing several critical technologies and to establishing the substantial transportation capabilities and orbital facilities is essential to the success of the Mars initiative. The Mars expeditions require the development of a number of technologies, including aerobraking (which significantly reduces the amount of mass which must be lifted to low-Earth orbit), efficient interplanetary propulsion, automation and robotics, storage and transfer of cryogenics in space, fault-tolerant systems, and advanced medical technology. ...It is clear that a robust, efficient transportation system, including a heavy-lift launch vehicle, is required.

**SSB: SPACE SCIENCE IN THE TWENTY-FIRST CENTURY**

In 1988, the Space Science Board (which became the Space Studies Board in 1989) of the National Research Council delivered a seven-volume report, *Space Science in the Twenty-First Century: Imperatives for the Decades 1995-2001*. This report was the result of a four-year study involving over one hundred scientists. A summary of the findings of this study, and the technology needs associated with the recommended courses of action follows.

### Overview

The Overview volume of the study includes a section on "Preconditions and infrastructure" that includes the following technology recommendations:

- Advanced programs for detector technology should be established and nurtured.
- Computer facilities in the space program must be maintained at state-of-the-art level, with regard to both hardware and software.
- There is a need for a sturdy, redundant system of acquiring access to space.

### Solar and Space Physics

The scientific objectives of solar and space physics will require missions to make *in situ* plasma measurements from near the surface of the Sun to the interstellar medium, remote sensing instruments for imaging, and active experiments for probing regions of the atmosphere and magnetosphere. The missions identified include:

- Solar Probe (perihelion distance 4 solar radii).
- Solar Polar Orbiter (circular solar orbit at 1 AU perpendicular to the ecliptic plane).
- Heliosynchronous Orbiter (25-day orbit at 30 solar radii).
- Interstellar Probe (to reach 100 AU in 5-10 yrs; velocity of 50-100 km/sec).
- High resolution solar telescopes (0.1 to 0.01 arcsec from UV to X-rays).
- Magnetospheric imaging instruments (from platforms on the moon, L4, L5, or L1).
- Active plasma physics experiments (interactions of plasmas with beams, waves, dust, and gas).
- Global Current Mission (approx. 300 probes to measure the electric and magnetic fields and electric currents).
- Orbiters for Mars, Mercury, and Jupiter (aeronomy and magnetosphere studies).

The technology development needed to accomplish these programs includes:

- Low-thrust propulsion systems for Solar Probe, Solar Polar Orbiter, Heliosynchronous Orbiter.
- Perihelion thruster for Interstellar Probe.
- Thermal protection for Solar Probe, Interstellar Probe, Mercury Orbiter.
- High-reflectivity multilayer coatings UV and X-ray mirrors for high-resolution telescopes.
- Radiation resistant electronic components for Jupiter Orbiter.
- Ultra-low-cost spacecraft for the Global Current Mission.
- Lagrangian platforms for magnetospheric imaging.
- Dust protection techniques for Jupiter Orbiter.
- Techniques and systems for active experiments including radar/lidar, dust and gas injectors, tethered satellites, high-power wave and beam injectors.

### Fundamental Physics and Chemistry

- Improved disturbance compensation systems for enhanced performance in a laser gravitational radiation observatory including both a reduction in disturbance level below  $10^{-10}/T^2 g/\sqrt{\text{Hz}}$ -spectral amplitude and extension of this performance for periods longer than  $10^4$ s.
- Frequency-stabilized single radial and longitudinal mode lasers of moderate power (100- to 1000-mW) for use in gravitational wave observations and optical interferometry.
- The ability to transfer liquid helium in space in order to replenish dewars for low temperature experiments.
- A spaceworthy hydrogen maser with a long-term stability of better than  $10^{-15}$  for relativity experiments. The development of trapped ion clocks with stability of  $10^{-17}$  to  $10^{-18}$ .

### Astronomy and Astrophysics

A major new direction for astronomy will be the use of interferometers in space. The goal is to achieve microarcsecond resolution over a broad wavelength range (radio to ultraviolet). Technical needs include:

- ▷ Structural technology - the construction, measurement, and control of large precision structures; the precision of control of pointing and momentum exchange; vibration minimization and decoupling; metrology for high-precision monitoring of structures.
- Optical technology - active systems, sensors, fiber optics, and image reconstruction.
- Station keeping technology - precision position and attitude control, quiet thrusters, orbital analysis, contamination control.

### Life Sciences

The life sciences report is sub-divided into five sections: exobiology, global biology, space biology, space medicine, and CELSS.

#### Exobiology

- Microchemical techniques for the identification of materials in individual microfossils.
- Highly sensitive mass spectrometric techniques for the identification of compounds and isotopes.
- RNA synthesizers, similar to those already available for the synthesis of DNA.
- Laboratory simulators for use in studying the course of chemical evolution.

- Collectors for cosmic dust particles.
- Rover technology.
- Technologies for the collection and handling of extraterrestrial samples.
- Telescopes (such as HST, SIRTf, and LDR) for the study astronomical objects for information about the origin of life.

#### Global Biology

- Spectrometers in the visible and near-ir with high spectral and spatial resolution.
- Color imagers with high spatial resolution.
- Laser fluorescence sensors for use in aircraft and spacecraft.
- Synthetic aperture radar for spacecraft studies of surface water and plant structure.
- Polarization photometers.

#### Space Biology

- The requirements for this subject concern instrumentation for the Space Station, including: plant growth chambers, animal holding facilities, sensimotor experiments, centrifuge, an area of very low gravity ( $10^{-6}g$ ) for the growth of crystals of proteins and nucleic acids.

#### Space Medicine

- Noninvasive imaging techniques (e.g., echocardiographs, ultrasound imagers, CAT scanners, NMR techniques).
- Physical monitoring and microchemical analysis techniques.
- Instruments for studies of immunochemistry and antibodies (e.g., laser cytofluorograph).

#### CELSS

- Plant growth chamber.

#### Planetary Science

- Low-thrust propulsion for serious study of comets, asteroids, and the outer solar system.
- Enhanced power sources for experiments.
- Cheaper landing technology so that arrays of instruments can be deployed on many bodies - including soft-landing technology, penetrators, rovers.
- Development of robotic or artificial intelligence technology so that spacecraft can make independent decisions.



- Radiation-hardened and high-temperature electronics for missions to Jupiter and Venus, respectively.
- On-orbit staging, assembly, and fueling for more ambitious missions, such as Mars sample return.

#### Other

There are a number of other technology issues that have been raised that are not explicit in the "Twenty-First Century" report. These include:

- The need for adequate launch capability to send missions into deep space without enduring very long trip times.
- Aerobraking technology.
- New sensor technology for Earth science missions.

### NASA CENTER SCIENCE ASSESSMENT REPORT

In 1986, NASA created a team to assess the state-of-the-science activities in its centers. The team's findings were published in 1988 and are given below.

#### Technology-Related Recommendations of the NASA Center Science Assessment Team

##### Interaction of Science & Technology

The Team notes the importance and complexity of establishing and maintaining close interaction between science and science-related technology at NASA Centers. The Team recommends that scientists be added to the advisory committees of the Office of Aeronautics and Space Technology (OAST), and that technologists be added to the advisory committees of the Office of Space Science and Applications (OSSA). Similar recommendations are offered to the National Research Council's Space Science Board (SSB) and Aeronautics and Space Engineering Board (ASEB). The Team also recommends the establishment of a NASA-wide Council on Science and Technology to exchange information on activities, needs, and interests in science-related advanced technology on a regular basis.

##### Technology Planning & Development

Technology planning for the long-term, for science missions and applications which are not yet approved programs and whose technical feasibility may not yet have been established, often requires estimates of user needs a decade or more before those programs reach the detailed design phase. The OAST planning process is initiated by systems studies of potential missions

to evaluate feasibility and identify enabling technologies needed to ensure system success. A set of technology "driver missions" is developed by OAST in cooperation with user program offices (OSSA for science missions) and agreed to by the program offices (again, OSSA for science). These driver missions provide the basis for joint technology plans which lead to a set of action strategies, joint OAST/OSSA planning workshops or working groups to identify needs, and identification of research programs for inclusion in the OAST program.

The Team found that the process does work. An example of a widely acclaimed successful collaboration between OAST and OSSA in advanced technology is the Sensor Working Group and the resulting sensor research program. The process is based on a multi-center, multi-office (OAST/OSSA) working group (with inter-agency and academic participation) that evaluates potential sensor research programs. By and large, the funded program is derived from their recommendations. Current sensor research and development is balanced between development of detectors, laser and tunable sources, submillimeter wave devices, and other sensors.

The extent to which the process can accommodate the needs of the science program is dependent on the needs identified by the OSSA program managers and on the ability of the OAST budget to respond. OAST updates annually in the set of RTOPs (Research and Technology Operating Plans) which commit funds to the current year of the long range plan. The OAST research program has a limited budget and a resultant inability to fund many of the programs recommended by the centers. The situation has been aggravated by reductions in advanced development budgets in OSSA. To alleviate this problem, NASA should provide budget support and flight priority for some flight demonstrations of selected advanced space technology activities. This will also help to bridge the technology transfer gap between OAST and OSSA (see below).

As future science missions become more firmly defined and nearer to approval, OSSA funds likely candidates for advanced systems with a transfer of technology from the OAST device-level research. Unfortunately, over the last decade, funding in user programs for supporting research has diminished, causing increased demands on the OAST advanced research budget which could not be met. As a result of these budget pressures, the OAST program has become focused on a more limited set of goals. Furthermore, a gap seems to have developed between OAST's carrying out work on device-level technology and the Agency's ability to incorporate such technology into flight systems.

The Team notes with approval that with renewed emphasis on strategic planning, agency-wide joint planning to identify advanced technology requirements for future missions is taking place. The Civil Space Technology Initiative which started in FY 1988 has an active involvement and shared management of its elements with user program offices. The Pathfinder technology program, proposed for FY 1989, has involved joint planning with user groups, particularly in the areas associated with the development of technology to support long-duration missions with humans in space.

The Team found that an excellent level of interaction and transfer of technology exists between the space science activities and those of the related advanced technology development organizations at each of the individual centers. This ability to call on the engineering expertise of the center in the conduct of the science activities is one of the unique strengths of the NASA

centers and an important factor in the attractiveness to scientists of the environment for doing science at NASA.

### **Impediments to Technology Transfer within NASA**

While technology transfer seems to take place within a given center, far less interaction occurs at the center-to-center level. Some positive actions include the Sensors Working Group and inter-center topical workshops. The Asilomar Workshops (1982, 1985, and September 1987) on the Large Deployable Reflector (LDR) brought together science and technology staff members to identify the enabling and enhancing technologies for the LDR mission and initiate plans for pursuing these technologies. Personal contacts also play a significant role at this level.

The Team noted that several potential impediments to effective technology transfer and a smooth flow of technology from development to use exist at the NASA Headquarters level. OAST concentrates on selected enabling and enhancing technologies for missions a decade or more in the future, while OSSA has nearer-term instrument and system needs. This difference in emphasis often results in a funding gap in the development of flight-qualified, state-of-the-art instruments, with neither office claiming responsibility for flight demonstrations of prototype hardware. A second possible shortcoming is that each office uses completely independent advisory groups. Thus, a technology program responsive to OAST's advisory structure may either not include, or include at a low priority, technologies that are needed to support the future science program.

The Team encourages OSSA and OAST to coordinate programs and development of advanced technology with mutual reviews.

## **REPORT OF THE ADVISORY COMMITTEE ON THE FUTURE OF THE U.S. SPACE PROGRAM**

The Advisory Committee on the Future of the U.S. Space Program, chaired by Norman Augustine, expressed concerns regarding the state of NASA's technology base and recommended a two- to three-times increase in the space technology budget. Table D-9 gives an excerpt of the report's findings.

### **AMERICA AT THE THRESHOLD**

In 1990, the President requested Lt. Gen. Thomas Stafford (USAF, Ret.) to lead a group, "The Synthesis Group," to synthesize the inputs from as wide a sector as possible of approaches to the conduct of the Space Exploration Initiative (SEI). This group delivered its report, *America at the Threshold* in 1991. The report identified seven functional areas in which technology development was required to support the SEI. They are propulsion, power, extravehicular activity, life support, planetary surface systems, spacecraft, communications, control and navigation. Of these, life support systems require both enhanced scientific understanding and

engineering development. Each contributes to space science and applications programs. Development on planetary surface systems likewise contributes to space science and applications programs. The remaining functional areas provide supporting technology that may also contribute to space science and applications, but in a more indirect sense.

The Synthesis Group identified the development of partially closed environmental control and life support systems as a critical objective. They would employ recycled air and water. Their development is a pacing element in the SEI and requires considerable antecedent scientific research.

Planetary surface technology is required for robotic orbiter and surface precursors, as well as for rovers systems. Table D-10 lists the principal technological requirements identified by the Synthesis Group.

Table D-9

Technology Findings of the Augustine Committee  
Technology Base

Next to talented people and a culture of excellence, the most important underpinning of the civil space program is its technology base. This base comprises the effort to develop key building blocks such as engines, computers, materials, and the like that enable significant new missions to be successfully undertaken. Unfortunately, this building block effort does not always compete favorably with the missions themselves in contending for funds and skilled personnel. Often, fundamental development programs are less glamorous, less visible, have no organized constituency, and generally are comprised of a number of small- and medium-size projects.

Nonetheless, the consequences of neglecting the technology base are very measurable indeed, not only impacting America's competitiveness but inducing major projects to be undertaken without a sufficient technological foundation in place. When problems are subsequently encountered, these projects must be restructured, usually accompanied by an increase in cost. The result is that major pursuits, with large work forces that cannot afford to be held in abeyance, siphon money from smaller research projects or from the technology base itself, and the whole cycle starts anew. It seems clear that our technology base, including its supporting facilities, must be revitalized and afforded priority commensurate with its importance if major new projects are to be pursued on a realistic basis in the decades ahead.

Recommendation 8: That NASA, in concert with the Office of Management and Budget and appropriate Congressional committees, establish an augmented and reasonably stable share of NASA's total budget that is allocated to advanced technology development. A two- to three-fold enhancement of the current modest budget seems not unreasonable. In addition, we recommend that an agency-wide technology plan be developed with inputs from the Associate Administrators responsible for the major development programs, and that NASA utilize an expert, outside review process, managed from headquarters, to assist in the allocation of technology funds.

On a related issue, the Committee is particularly concerned over the low priority that has been given to the development of the life support technologies, and to the fundamental medical aspects of long duration space flight by humans.

Table D-10

**Technology Recommendations of the Synthesis Group Relating to Planetary Surface Systems****Robotic Orbiter and Surface Precursors**

- Advanced imaging detectors, including improved charge-coupled device arrays and data-handling subsystems
- Compact multispectral imaging radar and Lidar for surface and subsurface characteristics
- Compact chemical analysis instrumentation, including gamma and x-ray spectrometers and imaging spectrometers
- Telerobotics and telepresence, including control architectures and supervised telerobotics, data handling, storage and virtual reality techniques
- Small spacecraft with gross masses less than 500 kg, including orbital "prospectors" and surface penetrators
- Autonomous systems to enhance Mars operation

**Rover Systems**

- Efficient regenerative fuel cells (1 Kw-hr/kg) with compact insulated cryogenic storage tanks
- Compact, specialized life support systems for short (two- to three-day traverses) duration, and portable radiation protection features
- Crew supported telerobotic surface driving systems and telerobotic extension systems with dexterous robotic manipulators
- Compact deployable photovoltaic arrays (200 W/kg or better)

## **APPENDIX E**

### **OSSA AND OAST TECHNOLOGY NEEDS MATRICES**

OSSA Technology Needs Matrix

OAST Strategic Civil Space Technology Initiative Categorization

Fiscal Year 1992 CSTI Funded Elements

Fiscal Year 1992 OSSA Prioritization of Division Technology Needs

Fiscal Year 1993 Congressional Request CSTI Elements

Fiscal Year 1994 CSTI Preview Budget Request

NASA Technology Needs Commonality

### Table E-1 OSA Technology Needs Matrix

## OSSA TECHNOLOGY NEEDS Grouped According to Urgency & Commonality

REVISED:  
NOVEMBER 18, 1991

High Frame Rate, High Resolution Video	2.5 - 4m, 100K Lightweight, PSR	Fluid Diagnostics	Real-Time Radiation Monitoring	Solar Array/Cells	Telebotics	High Trans-mission UV Filters
Cryogenic Systems .. Optics, coolers, shielding, PSR (SZ, SE, SL, SS)	Telescreens, Telepresence, & AI (SN, SL)	Rad Hard Parts & Detectors (SN)	(SB)	(SL, SZ, SE)	(SN)	(SZ)
Vibration Isolation Technology (SZ, SE, SL, SS)	Rel-Term Environmental Analysis (SB)	Space Qualified Inert & Ion Clocks (SZ, SL)	Solid/Liquid Interface Characterization (SN)	Laser Light Scattering Furnace (SN)	High Temperature Materials For Furnace (SZ)	K-band Transponders (SZ)
Extremes Upper Atmosphere Instrument Platforms (SZ, SE, SL, SS)	Batteries .. Long life time .. High energy density Control & Monitoring (SL, SZ)	Plasma Wave Antennas/Thermal (SZ)	Field Portable Gas Chromatographs (SB)	Advanced Purfacs Technology (SN)	3-D packaging for 1 MB Solid State Chips (SZ)	Rapid Subject Sample Delivery & Return Capability (SB) (SZ)
Mini/Microsystems .. Instrumentation, towers, descent images, camera, RTG, ascent vehicle/lander, S/C, payload (SZ, SE, SL, SS)	Low-drift Gyro, Trackers, Actuators (SZ)	Improved EVA Suli/PLSS (EMU) (SZ)	High Temperature Electronics (SL)	Non-Contact Temperature Measurement (SN)	Ultra-high Giga/bytes Telemetry (SZ)	Microbial Decontamination Methods (SB)
High Volume, High Density, High Data Rate On-board Storage & Compression (SE, SL, SN, SZ)	Microphonics Technology, FET development (SZ)	Auto SC Monitoring & Fault Recovery (SN)	Thermal Control System (SL)	Special Purpose Bioreactor Simulator Syst (SB)	Animal & Plant Reproduction Aids (SZ)	
Controlled Structures/ Large Antenna Structures Array/Deployable (SE, SZ, SL, SS)	X-ray Optics Tech .. imaging system .. low cost optics .. Bragg concentrators .. coded apertures (SZ)	SETI Technologies Regenerative .. Microwave & Optical/Laser Detection (SB)	Auto Rendezvous (SZ)	Auto Sample Monitoring Capability (SB)	Non-Destructive Coarse Dust Collection (SB)	
Large Filled Apertures .. lightweight & stable optics .. Cryo optical var., (ab., tent. .. Deformable mirror .. 13.2m PSR (SZ, SE, SL, SS)	Sample Acquisition, Analysis and Preservation (SB, SL)	32 Chz TWT Optical Communication (SL, SS)	Thermal Protection (SL)	Partial-g/jug Medical Care Delivery Systems (SB)	Dust Protection/Jupiter's Rings (SL)	
Ion Propulsion (NEP) (SL)	Radiation Shielding for Crews (SB)	SIS 3 The Heterodyne Receiver (SZ)	CBLSS Support Technologies (SB)			

SL: Life Sciences; SE: Earth Sciences and Applications; SL: Solar System Exploration; SN: Microgravity Sciences and Applications; SL: Space Physics; SZ: Astrophysics

Table E-2 OAST Strategic Civil Space Technology Initiative Categorization

# INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM 1992 STRATEGIC CSTI CATEGORIZATION

OAET

Technology	HIGHEST PRIORITY 000					2nd-HIGHEST PRIORITY 00					3rd-HIGHEST PRIORITY 0				
	Submillimeter Sensing	Direct Sensor Electronics	Mini/Micro-Instrumentation Laser Sensing	Active Microwave Sensing	Passive Microwave Sensing	Optoelectronics Sensing & Processing	Sample Acq., Analysis & Presentation	Space Science Technology	Planetary Surface Technology	Transportation Technology	Space Platforms Technology	Operations Technology			
	Cooler and Cryogenics	Microprecision CSI	Telescope Optical Systems	Data Archiving and Retrieval	Data Visualization & Analysis	Precision Instrument Pointing Systems	Sensor Optical Systems								
	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power	Planetary Rovers	Exploration Human Factors	---								
	---	Surface Solar Power and Thermal Mgt.	Extravehicular Activity Systems	---	In Situ Resource Utilization	Medical Support Systems	Laser-Electric Power Beaming								
	ETO Propulsion	Nuclear Thermal Propulsion	Nuclear Electric Propulsion	Transfer Vehicle Avionics	ETO Vehicle Avionics	Autonomous Rendezvous & Docking	COHE								
	Cryogenic Fluid Systems	Advanced Cryogenic Engines	Low-Cost ETO Transport	Aerobraking	CONE	---	TV Structures and Cryogenic Tankage								
	Platform Structures & Dynamics	Platform Power and Thermal Mgt.	Zero-G Life Support	Platform Materials & Environ. Effects	Station-Keeping Propulsion	Spacecraft On-Board Propulsion	Earth-Orbiting Platform Controls								
	---	---	Zero-G Advanced EMU	Platform NDE-NDI	Deep-Space Power and Thermal	Spacecraft GN&C	Debris Mapping Experiment								
	Space Data Systems	Space Communications Systems	Artificial Intelligence	Ground Data Systems	Optical Communications and Flight Expt	Space Assembly & Construction	Space Processing & Servicing Systems								
	---	Flight Control and Operations	TeleRobotics	Operator Systems and Training	Navigation & Guidance Systems	---	---								
					Flight Expts										

(Presented by OAST at the May 22, 1992 meeting of the Committee)

MARCH 23, 1992  
JCM-6800q

E-3



# INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM FY '92 CSTI FUNDED ELEMENTS

	HIGHEST PRIORITY			2nd-HIGHEST PRIORITY			3rd-HIGHEST PRIORITY		
Space Science Technology	Submillimeter Sensing	Direct Detectors	Laser Sensing						
	Cooler and Cryogenics	Microprecipitation CSI							
Planetary Surface Technology	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power					
			Extravehicular Activity Systems						Laser-Electric Power Beaming
Transportation Technology	ETO Propulsion	Nuclear Thermal Propulsion	Nuclear Electric Propulsion						
		Advanced Cryogenic Engines							
Space Platforms Technology	Platform Structures & Dynamics	Platform Power and Thermal Mgt.							
Operations Technology	Space Data Systems		Artificial Intelligence						
			TeleRobotics						

(Presented by OAST at the May 22, 1992 meeting of the Committee)

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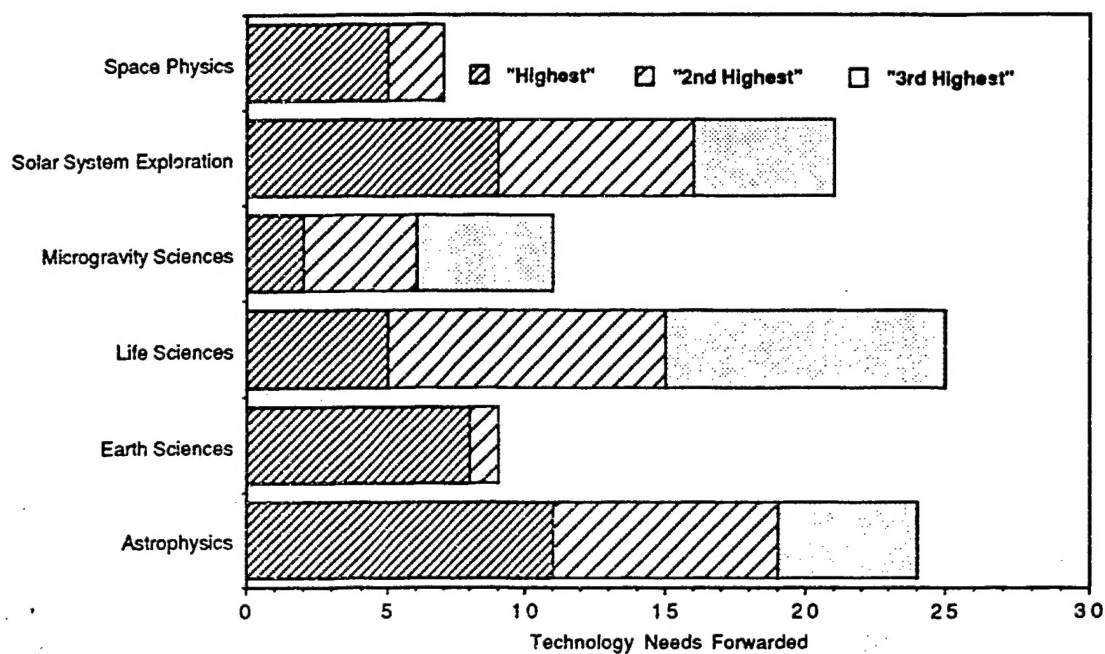


Figure E-1 FY 1992 OSA prioritization of division technology needs.

# INTEGRATED TECHNOLOGY PLAN FOR THE CIVIL SPACE PROGRAM FY '93 CONGRESSIONAL REQUEST CSTI ELEMENTS

	HIGHEST PRIORITY			2nd-HIGHEST PRIORITY			3rd-HIGHEST PRIORITY		
Space Science Technology	Submillimeter Sensing	Direct Detectors	Laser Sensing						
	Cooler and Cryogenics	Microprecipitation CSI							
Planetary Surface Technology	Radiation Protection	Regenerative Life Support (Phys-Chem.)	Space Nuclear Power (SP-100)	High Capacity Power					
			Extravehicular Activity Systems						
Transportation Technology	ETO Propulsion	Nuclear Thermal Propulsion	Nuclear Electric Propulsion						
		Advanced Cryogenic Engines	Low-Cost ETO Transport						
Space Platforms Technology	Platform Structures & Dynamics	Platform Power and Thermal Mgt.							
Operations Technology	Space Data Systems		Artificial Intelligence						
			TeleRobotics						

(Presented by OAST at the May 22, 1992 meeting of the Committee)

MARCH 23, 1992  
JCM-6800b

Table E-5 Fiscal Year 1994 CSTI Preview Budget Request

# FY 1994 CSTI PREVIEW BUDGET REQUEST

OAST

Technology	Submillimeter Sensing	Direct Detectors	Mini-Micro Instrument	Sensor Electronics	Microprocessor (CS)	Telescope Optical Systems	Laser Sensing	High Capacity Power	Planetary Rovers	E-7 Vehicle Avionics	Autonomous Landing	Deep-Space Power and Thermal	Advanced Refrigerator Systems	New Effort Augmented Effort Reroute
Space Science Technology	Cooler and Cryogenics	Space Nuc. Power (SP-100)	Microprocessor (CS)	Telescope Optical Systems	High Capacity Power	Planetary Rovers								
	Extraveh. Activity System	Regen. Life Support (Phys-Chem)	ETO Propulsion	Nuclear Thermal Propulsion	Nuclear Electric Propulsion	Low-Cost ETO Transport								
Planetary Surface Technology	ETO Propulsion	Cryogenic Fluid Systems	Platform Structures & Dynamics	Zero-G Life Support	Zero-G Advanced EMU	Space Comm Flight Control and Systems Operations	TeleRobotics							
	Artificial Intelligence													
Transportation Technology	Platform Structures & Dynamics	Zero-G Life Support	Zero-G Advanced EMU	Space Comm Flight Control and Systems Operations	TeleRobotics									
	Artificial Intelligence													
Space Platforms Technology	Platform Structures & Dynamics	Zero-G Life Support	Zero-G Advanced EMU	Space Comm Flight Control and Systems Operations	TeleRobotics									
	Artificial Intelligence													
Operations Technology	Platform Structures & Dynamics	Zero-G Life Support	Zero-G Advanced EMU	Space Comm Flight Control and Systems Operations	TeleRobotics									
	Artificial Intelligence													



(Presented by OAST at the June 11-12, 1992 meeting of the ASEB)

Table E-6 NASA Technology Needs Commonality  
INTEGRATED TECHNOLOGY PLAN FOR THE  
**NASA TECHNOLOGY NEED**

COMMON TECHNOLOGY NEEDS			OSO NEEDS	KEY COMMON TECHNOLOGY AREAS
OSSA NEEDS	OSF NEEDS	SEI NEEDS		
Advanced Data Systems	Vehicle Health Management	NASA/Synthesis SEI	High Data Rate Communications	ADVANCED EVA SYSTEMS
Advanced Space Structures	Advanced Turbomachinery Components & Models	Radiation Protection	Advanced Data Systems (Ground/Space)	REGENERATIVE LIFE SUPPORT
Robotics/Rovers	Combustion Devices	EVA Systems	Advanced Navigation Techniques	ADVANCED GN&C
Spacecraft Position/GN&C	Adv. Heat Rejection Devices	Regenerative Life Support	Mission Operations (AI, Software)	ADVANCED DATA SYSTEMS
Software/Data Visualization	Water Recovery and Management	Cryogenic Fluid Management		AUTOMATION AND ROBOTICS
Nuclear Electric Propulsion	High Efficiency Space Power Systems	Micro-G Countermeasure		AEROSPACE R&T (TPS, GN&C, Aerobraking)
Advanced Solar Arrays	Advanced EMU's	Surface Power (nuclear)		STRUCTURES AND MATERIALS
Radiation Shielding for Crews	Crew Training Systems	Auto. Rendezvous/Docking		ADV. SPACE POWER (Nuclear/Solar)
Auto. Rendezvous & Docking	Characterization of Al-U Alloys	Human Factors		THERMAL MANAGEMENT
Autonomous Landing	Cryogenic Supply, Storage and Handling	(Nuclear) Electric Propulsion		
Regenerative Life Support	Thermal Protection Systems	Synthesis SEI		
Advanced EMU's	Robotic Technologies	Heavy Lift Launch		
Micro-G Countermeasures	Guidance Navigation/Control	Telerobotics		
Sample Acquisition	Advanced Avionics Arch.	Materials and Fabrication		
Auto S/C Fault Recovery		NASA SEI		
High Rate Comm (Optical, Ka-Band)		Cryo. Space Engines		
High Energy Tech		Aerobraking		
Micro-G Medical Care		Surface Power (non-nuclear)		
Thermal Control		Autonomous Landing		
		Sample Acquisition/Analysis		
		Surface Mobility		
		Health Care		
		In-Space Construction and Processing		
These specific technology needs are (approximately) common across two or more Offices. The specific technology areas are shown, drawn from the various Offices' inputs			These General Technology Areas are Common to Three or more Offices	

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